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DEVELOPMENT OF CANONICAL MARINE AVIATION LOGISTICS SUPPORT PROGRAM II (MALSP II) DEPLOYMENT

by

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13. ABSTRACT (maximum 200 words)

This thesis develops and assesses possible Marine Aviation Logistics Support Program II (MALSP II) deployment configurations based on current allowancing procedures. MALSP II is intended to provide a more responsive logistics system with less sensitivity to variability in demand and trans-shipment times while reducing the logistical footprint. However, little work has been done on evaluating possible deployment models. We employ a Java-based discrete event simulation and implement a full-factorial experimental design to analyze how factors such as network complexity, distance, and number of aircraft affect the system's ability to support inventories of a total of 956 different repairable components. We investigate ideal locations to stage high-priority repair components in order to achieve best system performance, given limited resource allowances. By understanding the effects of different deployment configurations, we provide the Deputy Commandant for Aviation, the MALSP II Program Office, and Marine Aviation Logistics Squadrons with a model with which to train and provide decision makers with a better understanding of the MALSP II capabilities over the range of military operations.

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DEVELOPMENT OF CANONICAL MARINE AVIATION LOGISTICS SUPPORT PROGRAM II (MALSP II) DEPLOYMENT

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ABSTRACT

This thesis develops and assesses possible Marine Aviation Logistics Support Program II (MALSP II) deployment configurations based on current allowancing procedures. MALSP II is intended to provide a more responsive logistics system with less sensitivity to variability in demand and trans-shipment times while reducing the logistical footprint. However, little work has been done on evaluating possible deployment models. We employ a Java-based discrete event simulation and implement a full-factorial experimental design to analyze how factors such as network complexity, distance, and number of aircraft affect the system's ability to support inventories of a total of 956 different repairable components. We investigate ideal locations to stage high-priority repair components in order to achieve best system performance, given limited resource allowances. By understanding the effects of different deployment configurations, we provide the Deputy Commandant for Aviation, the MALSP II Program Office, and Marine Aviation Logistics Squadrons with a model with which to train and provide decision makers with a better understanding of the MALSP II capabilities over the range of military operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFAST	Aviation Financial Analysis Support Tool
ANOVA	Analysis of Variance
ARROWS	Aviation Readiness Requirements Oriented to Weapon Replaceable Assemblies Model
AVCAL	Aviation Consolidated Allowance List
BCM	Beyond Capable Maintenance
CCSP	Common Contingency Support Package
CONUS	Continental United States
CPI	Continuous Process Improvement
DOE	Design of Experiments
ELAT	Enterprise Logistics Analysis Tool
ESB	Enroute Support Base
FISP	Fly in Support Package
FOB	Forward Operating Base
FOSP	Follow on Support Package
FSA	Fly-in Support Allowance
ICA	Intermediate Level Contingency Allowance
IMA	Intermediate Maintenance Activity
MALS	Marine Aviation Logistics Squadron
MALSP II	Marine Aviation Logistics Support Program II
MCWP	Marine Corps Warfighting Publication
MOB	Main Operating Base
MOE	Measure of Effectiveness
MSA	Marine Air Group Support Allowance
NAMP	Naval Aviation Maintenance Program
NAVICP	Naval Inventory Control Point
NIIN	National Item Identification Number
NMC	Not Mission Capable
PCSP	Peculiar Contingency Support Package
PMALS	Parent Marine Aviation Logistics Squadron

PMC	Partial Mission Capable
ROMO	Range Of Military Operations
SPO	Service Planning Optimization
SSA	Strategic Support Allowance
T/M/S	Type/Model/Series
TRR	Time to Reliably Replenish
TRR_M	Time to Reliably Replenish Maintenance
TSA	Training Support Allowance

EXECUTIVE SUMMARY

This thesis develops and assesses possible Marine Aviation Logistics Support Program II (MALSP II) deployment configurations based on current allowancing procedures. MALSP II is intended to provide a more responsive logistics system with less sensitivity to variability in demand and trans-shipment times while reducing the logistical footprint. However, little work has been done on evaluating possible deployment models.

The Marine Corps is in the process of rewriting aviation logistics support doctrine. Legacy MALSP is inflexible for the wide Range of Military Operations (ROMO), and MALSP II still does not have a standard deployment configuration for the Marine Aviation Logistics Squadron (MALS) to train. Analyzing the design space within the realm of MALSP II concepts provides the aviation logistician with insight into supportable deployment configurations.

This thesis uses an object-oriented Java based discrete-event simulation to analyze the MALSP II deployment with respect to spare parts allowances. A spare parts allowance is the quantity of repairable components for which the MALS is authorized to store. The tool currently used to ideally distribute spare parts based on the Time to Reliably Replenish (TRR) or 90th percentile of resupply time, empirical demand data, and percentage of risk chosen by the aviation logistician, is the Enterprise Logistics Analysis Tool (ELAT). MALSP II and legacy MALSP allowances are compared with ELAT output and are simulated in order to assess supportable deployment configurations. MV-22 allowancing and demand data from MALS-26 in New River, North Carolina, are the inputs in the simulation.

To evaluate the performance of the allowance packages for each configuration, we examine three Measures of Effectiveness (MOE)—number of deficient allowances, supply effectiveness, and response time. An allowance is deficient if it is less than what the ELAT proposes as the ideal number of spare parts to support the aircraft at each node, also known as the buffer. Supply effectiveness is the number of immediate spare parts

issued from the node on which the aircraft is stationed, divided by the number of demands with MALSP II package allowances. Finally, response time informs how quickly the spare parts are issued to the squadron. Response time is measured in mean time an aircraft is waiting on a particular spare part.

All three MOEs include gross analysis where all demands are considered and net analysis where only demands with spare parts allowances are considered. We examine legacy MALSP and MALSP II allowance packages side by side to inform the impact of previous and proposed future allowances, respectively. All spare parts allowances are simulated against sixty-one possible logistic networks and aircraft configurations to assess a canonical MALSP II–style deployment and evaluate the MV-22 spare parts allowances as the complexity of the logistic network increases.

We find that an increase in an MOE does not always imply increased effectiveness in the different configurations. Allowances are limited, and even with high-risk demand filtering, not all ELAT suggested buffers are filled. The main factors that affect the MOE are number and placement of allowances and TRR. In general, as TRR decreases, supply effectiveness and response times improve. We review the performance of several configurations to determine the canonical MALSP II deployment design. This information assists with budgetary analysis and provides a network for which to train.

MV-22 MALSP II spare parts packages decrease in effectiveness as the nodes and number of supported aircraft become more complex. The legacy MALSP package also contains 1,414 more spare part allowances than MALSP II, but for all practical purposes, the MALSP II packages perform about the same as legacy MALSP packages. This demonstrates that having more allowances does not necessarily ensure better performance. Conversely, fewer quantities cannot always fill the buffer sizes proposed by ELAT.

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I. INTRODUCTION

A. THESIS PURPOSE

The Marine Corps aviation logistics community is undertaking a comprehensive doctrinal change. The Marine Aviation Logistics Support Program (MALSP), which is geared to support large-scale squadron-style deployments, is converting to the MALSP II, which accommodates a wider range of operational settings but is especially focused on supporting distributed operations and multiple, simultaneous deployments of small detachments of aircraft. The MALSP II deployment model leverages the most current logistic procedures to ensure the right number of people, parts, repair capability are stationed where needed when needed (MALSP II Project Office, 2010, p. 2). This ensures the proper mixture of support is available while also being scalable for the wide Range of Military Operations (ROMO). The *Marine Corps Vision & Strategy 2025* calls for a reduction in the deployed footprint and a reduction in resource requirements all while improving supportability.

This thesis investigates the advantages of the MALSP II logistics network design. Through simulation, we see the impact of strategically spreading the inventory throughout the logistics network thereby reducing the "iron mountain," minimizing resource requirements, and increasing supportability. On the basis of our analysis, we recommend that the MALSP II Program Office adopt a canonical deployment configuration in order to make all allowancing and budgetary decisions.

In addition, we examine the latest MALSP II spare parts packages for the MV-22. We find that while the legacy packages perform better in certain circumstances, the differences are not practically significant. In general, as the logistics network increases in complexity, the effectiveness of the spare parts packages decreases.

B. HISTORY OF MALSP

Since the 1980s, Marine Aviation Logistics has supported deployed operations with the MALSP. MALSP originated during the Cold War era as a means to support a squadron style deployment, ready to deploy in order to repel a Soviet Union invasion of

Western Europe. This large scale construct defended against the most dangerous threat during that time period. Threats have changed since the cold war and a flexible, scalable, more adaptable model supports a wider portion of the ROMO. Specifically, MALSP focuses on the high end of ROMO and is less flexible for smaller scale deployments.

Before MALSP a standardized deployment support model did not exist. The aviation logistician was responsible for using his/her experience to generate the assets required to support the operation. Of course, experience levels of all units were different and best practices varied throughout all the logistics squadrons. Therefore, a standard method of task organizing aviation logistics squadrons was developed to improve the reliability of aviation logistics support and help ensure critical support assets are not left behind.

Currently, Marine Corps aviation support consists of three levels including the organizational level, the intermediate level, and the depot level. The Naval Aviation Maintenance Program (NAMP) OPNAVINST 4790.2 defines each level of maintenance support thoroughly. The organizational level resides with the flying squadron and is responsible for identifying and scheduling necessary repairs and phase maintenance. As needs are identified, the maintainers produce a requisition which signals the supply system for replenishment. If the component required renders the aircraft inoperable, the aircraft is deemed Not Mission Capable (NMC), meaning the aircraft cannot fly until the component is replaced. If the component required only prevents certain missions from being flown, but not all, the aircraft is deemed Partial Mission Capable (PMC). NMC and PMC requisitions are considered "high priority" and the intermediate level responds as quickly as possible to equip the operational level.

The Intermediate Maintenance Activity (IMA) resides at the Marine Aviation Logistics Squadron (MALS). In addition, the MALS includes a supply department that stocks an inventory of repair components to support demand at both the intermediate and organizational maintenance activities. The IMA exists to repair damaged aeronautical components received from the organizational level, which are placed back in the supply department's warehouse, or returned to the organizational level. If the part cannot be repaired by the IMA, the part is shipped to the third level known as the depot level. The

depot level then repairs the component and returns it to the wholesale system or disposes of the component if it cannot be repaired.

The legacy MALSP foundation is based on a “push” system, where people, spare parts, mobile facilities, and support equipment are deployed to support the flying squadrons. The “push” system envisions massing support elements to be on-hand “just in case” the resource is required. See Figure 1 for a graphical representation of the support packages which support MALSP deployment. The design consists of predesignated aviation components set aside and pushed to theater.

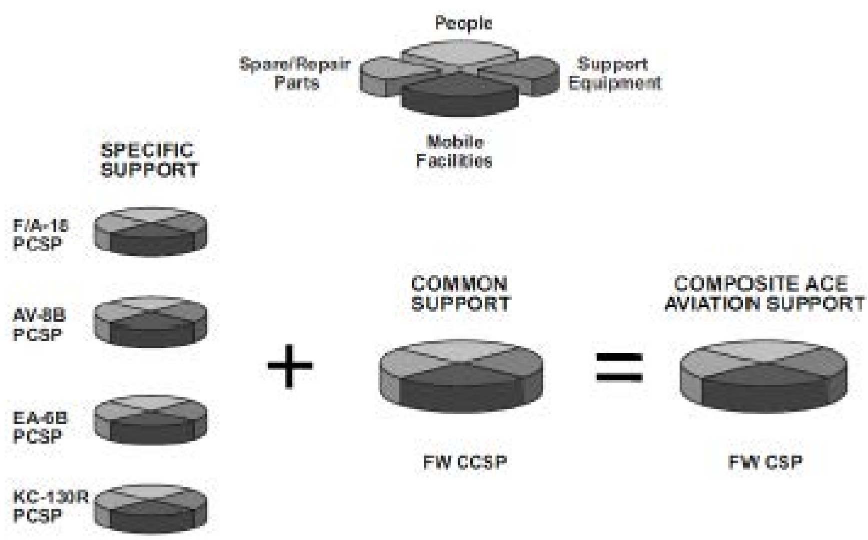


Figure 1. MALSP support package construct (from MCWP 3-21.2, 2002, p. 1–8)

The components of the legacy MALSP deployment for spare parts consist of different support packages known as the Fly in Support Package (FISP), Common Contingency Support Package (CCSP), Peculiar Contingency Support Package (PCSP), and Follow on Support Package (FOSP) (Marine Corps Warfighting Publication (MCWP) 3-21.2, 2002, 1–8, 1–10). The FISP is deployed first and designed to provide the first 30 days of spare part support to the squadron. During the initial 30 days, the MALS prepares a PCSP, consisting of a more robust support package, to the support the

deployed squadron. If more than one type of aircraft is deployed to the same region, the CCSP is also made ready and deployed. The CCSP contains those common repair components to multiple Type/Model/Series (T/M/S). Finally, the FOSP is deployed to sustain operations and is built for 90 days usage. The components of the legacy MALSP deployment illustrate the large scale "push" of spare parts and personnel to the specified region.

NAVICP determines spare parts allowancing, or the number of spare parts an activity is authorized to carry, for the legacy MALSP support packages, months or even years in advance. Therefore, little consideration is given to current spare part demand or the climate in which the aircraft are deployed. The model used to calculate the Aviation Consolidated Allowance List (AVCAL), which is all the spare parts authorized for each activity to carry, is the Service Planning Optimization (SPO) / Aviation Readiness Requirements Oriented to Weapon Replicable Assemblies (ARROWS). The models are designed to compute the allowance quantity with a 90% probability of the activity having the part on hand (Weapons System Support, N61 2015). The output from the SPO/ARROWS allowancing models are then used to design the FISP, PCSP, CCSP, and FOSP.

The packages are further broken down to repairable components, field level repairable components, and consumable components. Each category of component has a different requirement for the MALS supply officer to adjust allowances based on evolving demand from the flying squadrons. Repairable components have the strictest policy when it comes to allowance adjustment at the MALS. These are generally the most expensive, largest spare parts and repair of these components is deemed economical. When a repairable component is requisitioned by the flying squadron, the squadron is responsible to "turn in" that component to the IMA for repair. If the component can be repaired, it is returned to the supply officer's warehouse. If the component cannot be repaired, the item is considered Beyond Capable Maintenance (BCM) and referred to the Depot Level for overhaul or disposal. Allowance increase requests for repairable components require approval from the Naval Inventory Control Point (NAVICP). Field level repairable components are also returned to the IMA for repair, however if repair is

not possible, the item is disposed of at the Intermediate Level. Lastly, consumable items are relatively cheaper items which are disposed of by the flying squadron when replacement is required. Therefore, the category of component restricts the supply officer's ability to adjust allowances.

C. BACKGROUND OF MALSP II

The future of Marine Corps aviation logistics deployed operations is MALSP II. MALSP II is a designed nodal network which is scalable to meet most requirements of the ROMO. The MALSP II construct affords the aviation logistics community with a more capable and efficient support ability by reducing the aviation logistics' "footprint" of forward deployed equipment while improving responsiveness (MALSP II Project Office Capstone Document, 2012, p. 9). Increased capabilities are achieved by leveraging the latest technology and supply chain management. MALSP II utilizes a "pull" system, which uses demand data to harness only the support equipment and spare parts necessary to support operations.

The MALSP II model implements a nodal network design that provides more protection against variance in demand, as well as variance in shipping time for replenishments. The nodal network consists of a Parent Marine Aviation Logistics Squadron (PMALS), Enroute Support Base (ESB), Main Operating Base (MOB), and Forward Operating Base (FOB). See Figure 2 for a graphical representation of the MALSP II nodal network.

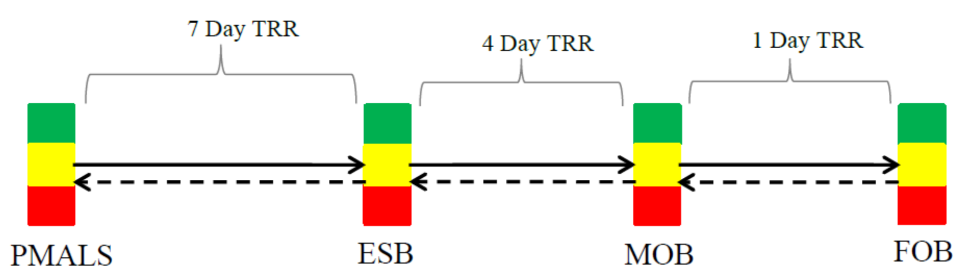


Figure 2. Notional graphical display of a MALSP II nodal network (from Seagren, 2013, p. 10)

In Figure 2, each node represents a separate geographical location. The colored boxes represent spare part's buffers, which are the number of spare parts stored at a node, and the associated level of risk. The Time to Reliably Replenish (TRR) the next buffer from left to right is the actual time it takes for spare parts to arrive at the next node 90 percent of the time. That is to say that 90 percent of all spare parts shipped from the PMALS to the ESB arrive in seven days or less. The solid arrows represent spare parts shipped between the nodes, while the dashed line represents demand signals. When a demand signal originates from the FOB, all the previous nodes (PMALS, ESB, and MOB) with stock ship the required spare parts to the next buffer, to its right. The PMALS is resupplied from the wholesale system to ensure all buffers at each node are met.

The four types of buffers or nodes are leveraged to minimize the amount of time the flying squadrons are waiting are spare parts. The PMALS are, for the most part, located in the Continental United States (CONUS) (MALSP II 2012, p. 15). This is where the majority of repair capability for the repairable and field level repairable components resides. The ESB is a supply hub designed to connect the PMALS and MOB to produce smaller TRRs to the MOB. The MOB is located in theater and supports flying squadrons while also shuttling required spare parts to the FOB. The FOB is located at "the tip of the spear" and supports the furthest deployed unit. All components of the nodal network support each other in order to reduce aircraft down time.

The PMALS only has a limited number of allowances that can be used to fill the buffers at the ESB, MOB, and FOB. This requires the aviation logistician to strategically place all allowances throughout the nodal network in order to best support the squadrons. The tool currently used to distribute allowances based on TRR, empirical demand data, and percentage of risk chosen by the aviation logistician is the Enterprise Logistics Analysis Tool (ELAT). ELAT captures demand data and TRR's from the Aviation Financial Analysis Support Tool (AFAST) and uses the information to calculate buffer sizes. The buffer sizes are further adjusted based on the percentage of risk the supply officer is willing to accept. In practice, supply officers generally lean towards high risk as

allowances are limited, thus helping spread the parts to as many nodes as possible (Seagren 2013, p. 15).

Allowancing for the PMALS is derived in much the same way in MALSP II as it was for MALSP. NAVICP utilizes the same model in SPO/ARROWS to calculate the allowances for the packages within MALSP II. The packages however have different names such as the Fly-in Support Allowance (FSA), Marine Air Group Support Allowance (MSA), the Intermediate Level Contingency Allowance (ICA), and the Strategic Support Allowance (SSA), and Training Support Allowance (TSA). The FSA is designed to support a specific number of deployed aircraft approximately 30 days, similar to the FISP in MALSP. However, the main difference between the FISP and the FSA is that the FSA is not protected in peacetime/stateside to the same extent as the FISP. The MSA provides allowances for a specific T/M/S and is designed for 90 days of support. The ICA package provides allowances to repair items inducted at the IMA. The MALSP II support packages are combined at the PMALS and distributed through the nodal network using tools like ELAT to ensure spare parts are located at correct node when needed.

The legacy MALSP FISP consists of spare part allowances for a predesignated number of aircraft for thirty days. A FISP is therefore difficult to split when a fraction of a squadron is sent to one location while another fraction of a squadron is deployed to a different location. This is because many National Item Identification Number (NIIN) or items contain only a single allowance and both locations cannot have the single item simultaneously. The modular design of the FSA attempts to better account for this by creating packages consisting of three sets of four aircraft FSA's. The modular design allows for easier part distribution across multiple small detachments.

Another issue with the current NAVICP allowancing algorithms is that they focus on supply effectiveness versus response time. Supply effectiveness is the percentage of requisitions the MALS fulfills immediately from the supply officer's shelf (Weapons System Support N61 2015). The MALSP II concept focuses on response time, which captures the time aircraft spend waiting for parts.

MALSP II is designed to buffer against variance in demand with deployed operations by leveraging the most current logistical tools available. Using tools like ELAT, only the parts needed based on current demand data reside at each node within the network. Spare part allowances are further scrutinized based on TRR to decrease aircraft downtime and buffer against demand variance. Also, by placing the majority of repair capability at the PMALS and only deploying parts with current demand data, the iron mountain of needless gear is greatly reduced. Inventory management requirements are also reduced further. The demand pull system is scalable, flexible, and more manageable.

D. SUMMARY

The Marine Corps is in the process of rewriting aviation logistics support doctrine. Legacy MALSP is inflexible for the wide range of ROMO and MALSP II still does not have a standard deployment configuration for MALS' to train for. Analyzing the design space within the realm of MALSP II concepts provides the aviation logistician with insight into supportable deployment configurations based on current allowance support packages. Further, the stochastic simulation quantifies high risk spare part response time throughout the supply chain network.

II. LITERATURE REVIEW

A. CONTINUOUS PROCESS IMPROVEMENT OF LOGISTICS SYSTEMS

Technology and supply chain management processes are improving constantly, and Marine Corps aviation logistics must adopt a flexible strategy, and harness modern supply chain logistic procedures, to achieve the most efficient and cost effective logistics network. Continuous Process Improvement (CPI) or AIRSpeed is the approach that the Marine Corps logistics community employs to leverage current strategies in commercial business (Apte & Kang, 2006, p. 18). Theory of Constraints, lean thinking, and six sigma concepts comprise the CPI strategy in aviation logistics and are incorporated in the MALSP II framework to improve the supply chain network's overall performance (Steward 2008, p. 41). Marine Corps aviation logistics is in the process of implementing CPI's to improve the end-to-end aviation logistics supply chain.

A supply chain is a complex dynamic network involving the flow of information, material, and funds (Ahn, Lee, & Park, 2003, p. 1). The management of the supply chain is extremely challenging when considering large inventories and inconsistent customer demand (Mahaptra, Yu, & Mahmoodi, 2012, p. 1). Excessive inventories create a burden on the manager because they need larger storage facilities and more personnel to keep accountability. The issue is further complicated with deployed supply chains because often times the management is done in an austere, hostile environment where the supplies are susceptible to attack.

Marine Corps aviation logistics is shifting from a "push" supply chain network to a "pull" supply chain network. This direction change in doctrine is a tough sell to leaders and the maintenance community who generally think more gear is better (Steward, 2008, p. 42). Changing cultural behavior can be difficult, but many successful examples of "pull" supply chain networks exist in practice and in literature. Small isolated MALSP II experiments have been attempted with encouraging results; however, little work has been done on large scale military supply chain networks. Simulation of large scale military

logistic scenarios is a cost effective procedure while also helping to identify improvements employing CPI processes.

B. THEORY OF CONSTRAINTS / LEAN / SIX SIGMA

Theory of constraints, lean thinking, and six sigma currently comprise the foundation of Marine aviation logistics' CPI processes. Theory of constraints is the process of breaking the logistics system up into interdependent processes and then determining the weakest link (Nave, 2002, p. 75). After the constraint has been identified, it can then be improved upon, thereby increasing the effectiveness of the entire system. The process of identifying the weakest link and improving the constraint is repeated over and over throughout the lifetime of the system.

Lean thinking focuses on the removal of anything that does not create value to the end item or process (Nave, 2002, p. 75). The idea is to perfect the process by creating a more efficient process. As items spend less time in the system, the overall process becomes less costly.

Six sigma focuses on the reduction in errors within the system as a whole. However, the system and all the processes must be understood in order to reduce the variation within the process (Nave, 2002, p. 75). When the causes of variation within the system are understood, steps can be taken to standardize the process. The predictable process can then be examined and changed producing less unexpected results, thereby increasing reliability.

C. FROM MALSP "PUSH" TO MALSP II "PULL" LOGISTIC NETWORKS

The "push" supply chain consists of building up the inventory as much as possible in order to have it when needed. In the civilian sector, "widget retailers project how popular widgets will be, push them onto the consumer and, if they guess wrong, end up with a full stock rooms and fire sales" (Aron, 1998, p. 58). Here, the burden is on the retailer who misses out on potential profits if the gear is not sold. In aviation logistics, it equates to larger storage facility requirements, more personnel required to manage the gear, and greater effort needed to redeploy and offload the unused gear. Thus, large

inventories are costly to manage. Projections about the amount of gear needed to meet demand is based on averages of past demand data. Furthermore, average demand data does not allow for a rapidly evolving demand pattern (Simchi-Levi, Kaminsky, & Simchi-Levi, 2008, p. 188).

In aviation logistics the MALSP deployment model follows the “just in case” mentality (Steward, 2008, p. 40). Inventory managers desire as many spare parts and repair capability as possible to increase operational readiness. When spare parts become obsolete as airframes improve, waste is produced. Large quantities of gear are also thought to protect against the possibility of unusually high demand, but instead the extra gear is burdensome and vulnerable to attack within a combat zone. The “push” supply chain is therefore not cost effective or efficient for inventory managers.

A “pull” supply chain uses true customer demand instead of forecasted demand in order to send only the gear needed by the customer (Simchi-Levi et al., 2008, p. 189). Instead of having packages based on average monthly demand like legacy MALSP, MALSP II uses a series of buffers utilizing the TRR. The focus on MALSP II is to use the most current demand data and drive down replenishment times. The network of buffers is constantly evolving in order to support the variance and infrequency in demand data.

D. EXPERIMENTATION AND SIMULATION WITH RESPECT TO MALSP II

In theory the MALSP II deployment model provides smaller lead times to critical aviation spare parts. However, only small experiments have been conducted with positive results. In 2005, a pilot program was launched consisting of 273 consumable NIIN’s to Al Asad, Iraq. In two years, the pilot program successfully filled all mission degrading requirements except for one (Steward, 2008, p. 42). The results are impressive, but not completely convincing because of high level of attention paid to such a small population. Thus, simulation is an important tool to help validate the whole supply chain.

Logistics problems are often large and extremely difficult to solve analytically because of their complex nature. The problems are difficult because there is a large

decision space, numerous decision makers, and uncertainty (Pokahr, Braubach, Sudeikat, Renz, & Lamersdorf, 2008, p. 1). The decision space consists of a large amount of decision variables which produce complex problems quickly. The key is figuring out the most important factors to examine. Within the logistics network are numerous decision makers with different responsibility that further complicate the problem. Lastly, uncertainty exists in all logistics environments and is difficult to model (Pokahr et al., 2008, p. 2–3). Instead of conducting a large real world experiment, computer simulation with strategically selected factors, can produce relevant insight into the effectiveness of the supply chain network.

Many logistic planning software tools exist on the market today, but they are far from providing optimal solutions (Davidson, & Kowalczyk, 1997, p. 3). Even fewer logistics planning software tools exist for military application. In this thesis we examine the MALSP II deployment model with a JAVA based discrete event simulation. Key factors such as deployment configuration, TRR, and specific NIIN data are used to provide key insight into the effectiveness of the model as it is expanded.

E. SUMMARY

CPI is the foundation for which MALSP II continues to evolve. The theory of constraints, lean thinking, and six sigma concepts inherent in the MALSP II concept ensure the system as a whole continues to improve efficiency. The flexible nature of MALSP II allows the network to improve as better techniques are discovered.

Large scale supply chain networks are difficult to solve analytically, however; simulation provides important insight to the interworking of the complex system. Simulations can also be conducted at relatively low cost provide real world solutions tailored to specific needs.

III. JAVA-BASED DISCRETE EVENT SIMULATION MODEL

A. PURPOSE OF THE SIMULATION

This thesis uses an object-oriented Java based discrete-event simulation to analyze the MALSP II deployment. MALSP II and legacy MALSP spare parts packages are compared with ELAT output and are simulated in order to assess the supportable deployment configurations. MV-22 allowancing and demand data from MALS-26 in New River, North Carolina, are the inputs in the simulation.

We examine each repairable item's allowance and demand data independently. This model examines the quantity of spare parts and their ability to support a wide range of deployment configurations from only the PMALS to a network of a PMALS, an ESB, two MOB's, and four FOB's (See Figures 3, 4, 5, and 6). We employ the simulation model to assess the supportability of allowancing with different configurations and give the MALS something to train to.

From the AFAST database we derive the demand history for each of the seven MV-22 squadrons that MALS-26 supports for a two-year time period from 2010 to 2012. This thesis focuses on only the high priority, repairable aircraft parts, because these are components that most directly impact flight line readiness.

B. MODEL INPUTS

This thesis uses Seagren's (2013) Discrete Event Simulation of the MALSP II Logistical Support. It is implemented in Java and uses SimKit (Buss 2002, p. 243–249) extensively. The object oriented simulation models elements within MALSP II style deployment that resembles reality with fairly high fidelity. Each node (PMALS, ESB, MOB, FOB) within the model is represented by an object that manages a local inventory of parts. If aircraft are present at the node, the node object also supports the local demand from those aircraft. In addition to managing their local inventories, the node objects communicate with each other in a variety of ways, to include referring spare part demands to each other, processing lateral support requests, and forwarding

replenishments. The model output includes comprehensive demand history, history of every document, as well as inventory levels over time.

The input factors within the model are NIINs, deployment configurations, TRR between nodes, and the spare parts package. The following is an introduction and explanation of the important input parameters:

1. NIINs

From AFAST we gather 954 individual NIINs with at least one demand in the two year timeframe. Each NIIN is independent within the model.

2. Modeling Spare Part Demand

The demand for a particular NIIN is modeled as a Poisson Process. The frequency of events over time is often modeled as a Poisson Process with Exponential Inter-arrival times (Law & Kelton 2003, p. 325). The parameter λ represents the daily rate at which demand is generated. We calculate average daily demand for each item from AFAST data and take the reciprocal in order to obtain λ. The rate at which demand is generated is also appropriately scaled for the number of aircraft at each node using the fact that the inter-arrival times are Exponentially distributed with mean $(1/\lambda)$. For example, eight aircraft deployed to a MOB generate demand at a rate of $8*\lambda$ (Seagren 2013, p. 26).

3. Modeling BCM Rate

The expected probability an item is declared BCM equals the number of times the item was BCM, according to the AFAST data, divided by the total number of requisitions. Recall an item is BCM when the IMA cannot repair the damaged spare part and a replacement component is referred to the wholesale system. We calculate BCM rates separately for each NIIN and determine the percentage of time the part is repaired or referred to the wholesale system. In this model, if repair data was not present in AFAST, then the spare part is always BCM, spending no time in repair, and is subjected to a standard 25 day TRR for replenishment from the wholesale system.

4. Modeling Maintenance Time

For this thesis, the Time to Reliably Replenish Maintenance (TRR_M) uses a triangular distribution. This allows us to set a defined minimum and maximum and assign the mode in such a way that a component with repair capability is repaired in the required time frame: 90% of the instances, in the assigned time or less. For simplicity, we have chosen 28 days as the TRR_M, meaning 90% of instances where the spare part is repaired, it is done so in 28 days or less. Repairable components are generally repaired quickly, therefore the max is set to 41 days while the min and mode are zero days.

5. Buffer Sizing

Buffer sizing is an extremely important within the MALSP II construct because it helps protect against variance in demand. Each node within the deployment structure has a buffer size set based on TRR and local demand. The tool aviation logisticians use to determine buffer sizes is ELAT. This thesis uses a JAVA based algorithm which applies the same principals as ELAT in practice because the actual program was not available (Seagren 2013, p. 31–32). ELAT projects the number of spare parts required at each node based on empirical demand data from AFAST, the TRR between the node and its parent, and risk percentage selected by the logistician. High risk is generally chosen by logisticians due to resource constraints and is used in this model. The number of legacy MALSP and MALSP II spare parts packages do not always allow for full buffers due in part to the difference in SPO/ARROWS allowancing algorithms.

Filling all buffers is challenging due to limited allowances in some cases. This model gives priority in the following manner:

1. FOB
2. MOB
3. ESB
4. PMALS

That is to say that the FOB buffers are filled first, followed by the MOB, then the ESB, and finally the PMALS when the configuration supports each node. The FOB, MOB, and ESB are given priority because in practice deployed squadrons are given priority due to the importance of the mission. For example, if ELAT suggests one spare

part for each node in the system, the FOB, which is the most forward deployed node, would be the only node to receive the spare part. When more than enough inventory exists to fill all ELAT buffers, 25% of the remaining is added to the MOB and the rest are sent to the PMALS. These business rules are chosen in part to simplify the distribution of spare parts and resemble reality. This technique is a heuristic, but it provides desired insight without degrading the output.

6. Deployment Configurations

We examine eleven different node configurations shown in Figures 3, 4, 5, and 6. Although only the "a" configurations are shown, all thirty-one configuration combinations are explored and can be seen in Table 1. The majority of the analysis focuses on the "a" configurations because the larger number of aircraft provides the most insight. Also, the ESB does not directly support aircraft.

Table 1. DOE aircraft assignments at each node

1	PMALS							
a	78							
2	PMALS	MOB						
a	68	10						
b	72	6						
c	76	2						
3	PMALS	ESB	MOB					
a	68	0	10					
b	72	0	6					
c	76	0	2					
4	PMALS	MOB	FOB					
a	68	8	2					
b	70	6	2					
c	74	2	2					
5	PMALS	ESB	MOB	FOB				
a	68	0	8	2				
b	70	0	6	2				
c	74	0	2	2				
6	PMALS	MOB	FOB	FOB				
a	68	6	2	2				
b	70	4	2	2				
c	72	2	2	2				
7	PMALS	ESB	MOB	FOB	FOB			
a	68	0	6	2	2			
b	70	0	4	2	2			
c	72	0	2	2	2			
8	PMALS	MOB	FOB	FOB	FOB			
a	62	6	4	4	2			
b	66	4	4	2	2			
c	70	2	2	2	2			
9	PMALS	ESB	MOB	FOB	FOB	FOB		
a	58	0	10	4	4	2		
b	62	0	8	4	2	2		
c	68	0	4	2	2	2		
10	PMALS	MOB	FOB	FOB	MOB	FOB	FOB	
a	58	6	2	2	6	2	2	
b	62	4	2	2	4	2	2	
c	66	2	2	2	2	2	2	
11	PMALS	ESB	MOB	FOB	FOB	MOB	FOB	FOB
a	58	0	6	2	2	6	2	2
b	62	0	4	2	2	4	2	2
c	66	0	2	2	2	2	2	2

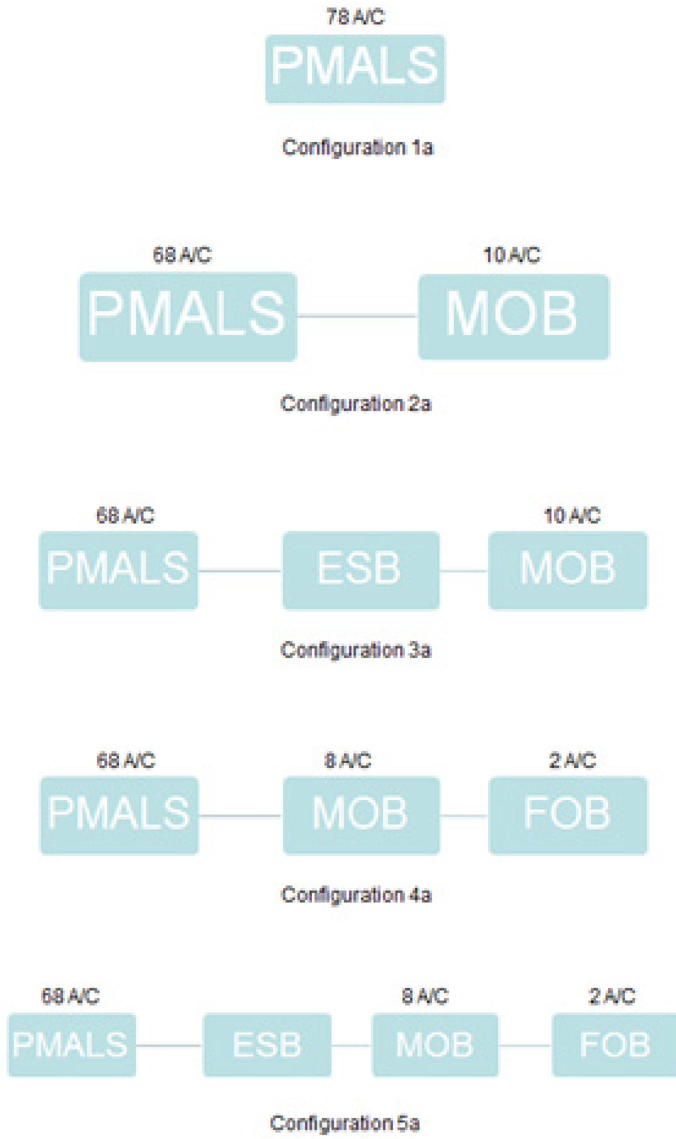


Figure 3. Configurations 1a, 2a, 3a, 4a, and 5a

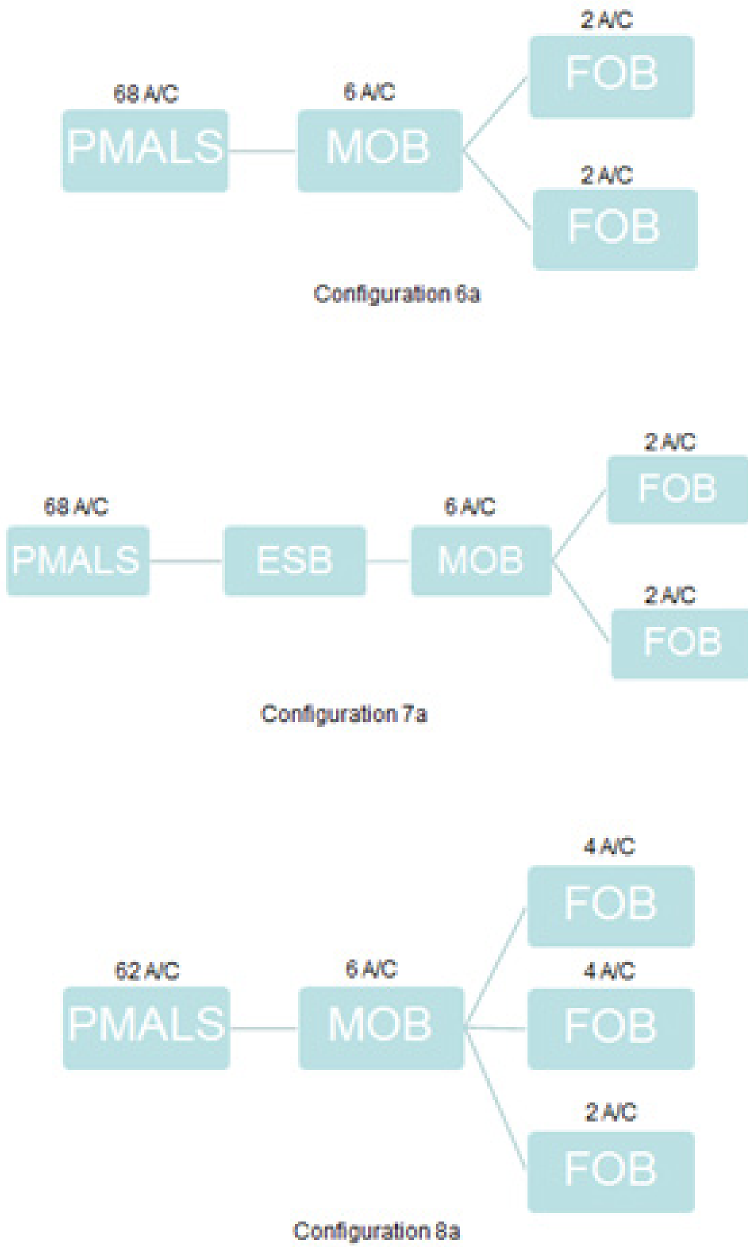
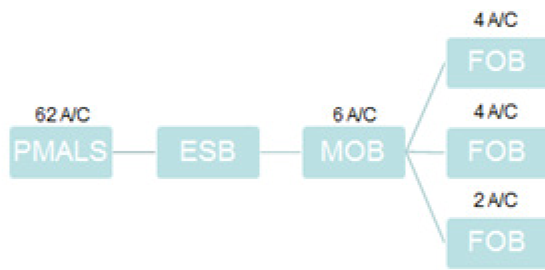
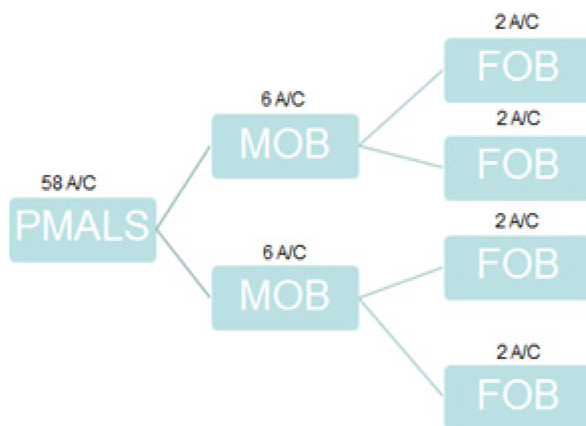


Figure 4. Configurations 6a, 7a, and 8a

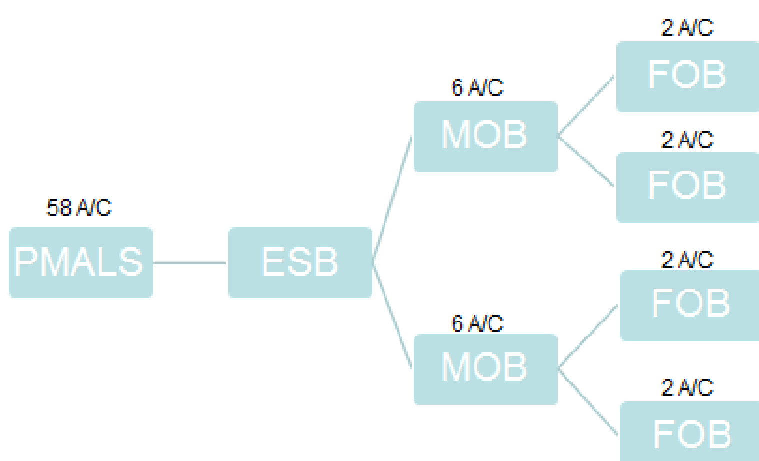


Configuration 9a



Configuration 10a

Figure 5. Configurations 9a and 10a



Configuration 11a

Figure 6. Configuration 11a

7. Shipping Time between Nodes

We employ the Lognormal distribution to model inter-nodal shipping times because it most closely resembles empirical inter-nodal shipping times (Seagren 2013, p. 29). This distribution is valid when observing "the time to perform some task … [and] quantities that are the product of a large number of other quantities (by virtue of the Central Limit Theorem)" (Law & Kelton, 2003, p. 307). This thesis investigates the impact of a high and low TRR. See Table 2 for the TRRs.

Table 2. TRRs for 90th Percentile of node-to-node shipping time

TRR	From/To Nodes		Days
Low	PMALS	MOB	5
	PMALS	ESB	4
	ESB	MOB	2
	MOB	FOB	1
High	PMALS	MOB	10
	PMALS	ESB	8
	ESB	MOB	4
	MOB	FOB	2

The simulation expands on Seagren's (2013) report entitled "Modeling & Simulation in Support of MALSP II Report of Findings." A detailed explanation of the model setup can be found in Chapter II of his report.

C. FULL FACTORIAL DESIGN OF EXPERIMENTS

The full factorial Design of Experiments (DOE) contains 954 independent NIIN's, eleven deployment configurations with three levels of varying aircraft at each node, a high and low TRR (see Table 2 for each configuration), and legacy MALSP and MALSP II spare parts packages. Totaling all factors provides 116,388 design points which are replicated 30 times each. Each run simulates the performance of a single item over the course of a two year deployment. With all the design points and replications, an experiment takes approximately 8 hours to complete on a desktop computer with a 1.90 GHz processor. See Figure 3 for a graphical representation of the deployment network.

See Table 1 for number of aircraft deployed to each node for the configuration under consideration.

Of note, MALS-26 possesses six deployable squadrons of ten aircraft each, and one training squadron of eighteen aircraft. For this model, the minimum number of aircraft deployed is zero aircraft, when considering only configuration one, or two aircraft when considering any other configuration. The max number of deployed aircraft for the largest configuration is twenty aircraft or two squadrons.

Each configuration has a quantity of spare parts stored at each node. The number of total spare parts for the whole network of nodes is retrieved from the packages contained in AFAST data. The legacy MALSP package includes one 24 plane PCSP, one 36 plane PCSP, one 24 plane FISP, one FOSP and one 20 plane TSA. The MALSP II package includes one 78 plane MSA, one ICA, one SSA, and two FSA. Each spare parts package contains a number of authorized spare parts, which the aviation logician distributes to the deployed nodes based on ELAT output. The ELAT output creates the buffer at each node and the inventory of spare parts from the allowance packages fills the buffers. Analyzing both packages side by side provides insight into the way in which NAVICP continues to assign allowances. The legacy MALSP and MALSP II spare parts packages are then compared alongside ELAT requirements to analyze the effectiveness

We employ the variance reduction technique of common random numbers in this simulation. The common random numbers' variance reduction technique is appropriate when "comparing two or more alternative system configurations" (Law & Kelton, 2003, p. 578). This reduces the variance between replication caused by different random number seeds.

D. MEASURES OF EFFECTIVENESS

To evaluate the performance of the spare parts packages for each configuration, we examine three Measures of Effectiveness (MOE)—number of deficient NIINs, supply effectiveness, and response time.

1. Deficient Items

In this thesis, an item is deficient if it is less than what ELAT proposes to fill the buffer. For example, for a given NIIN and configuration, ELAT proposes an ideal buffer size for each of the nodes in the system. We sum up all the ideal buffer sizes and then compare them to the total spare parts available, according to the packages. If the total number of spare parts in the packages is less than the total ideal buffers, the NIIN is deficient.

2. Supply Effectiveness

Supply effectiveness is the MOE which legacy MALSP is generally graded. Supply effectiveness is further broken down to measure the gross and net supply effectiveness of spare parts packages. Gross supply effectiveness is the overall percentage of those spare parts immediately issued from the node to the flying squadron divided by the total number of demands. If the supply department does not have the item currently on hand that the squadron desires, the gross supply effectiveness decreases. Net supply effectiveness is the measure of spare parts the MALS has allowances for and which are immediately issued; divided by total number of demands for the gear with allowances.

In this thesis we are mainly concerned with net supply effectiveness and that is analyzed in Chapter IV. Aviation logisticians are interested in net supply effectiveness because it measures the MALS on the spare parts for which they have allowances. The NIINs have allowances because, for the most part, enough demand has occurred for that particular item in the past. The weakness of net effectiveness is that it encourages the behavior of increasing inventory to increase net supply effectiveness. Also, supply effectiveness ignores the time domain in that it does not measure the amount of time an aircraft waits for a part that was not immediately fulfilled.

3. Response Time

The third MOE is response time which informs how quickly the spare parts are issued to the squadron. Response time is measured in time an aircraft is waiting for a spare part or document days, by summing all the days the spare part is in transit to the node where the part was ordered.

We consider the response time for a given NIIN and are interested in the total response time a given node or collection of nodes. Response time can be thought of the average time an aircraft waits for a spare part. Response time provides a better overall assessment of the network as a whole because time is considered and not just if the spare part is present or not like in the net supply effectiveness MOE.

E. ASSUMPTIONS AND LIMITATIONS

The assumptions in this model prevent the simulation from becoming unwieldy and are necessary to allow the simulation to complete in a reasonable timeframe. The following assumptions are included in the model:

1. The communication within the nodal network is instantaneous. Sometimes deployed units experience communication delays due to the austere environment. This is difficult to model and does not add or detract from the desired results.

2. The simulation begins with all nodes containing all the spare parts needed to fill the allowances within the spare parts packages. In reality the nodes never have full spare part buffer quotas due to backordered items, lost inventory, or repair of the component is taking place in the IMA. We are interested in the effectiveness of the network and this does not detract from the outcome.

3. Only high-priority repairable spare parts are considered in this model. These are generally the limiting factors in logistics support due to high cost and limited spare parts.

F. SUMMARY

The discrete-event simulation uses high fidelity to model the real world deployment configuration possibilities in order to gain insight into what is supportable with current spare parts package structures. The full factorial DOE provides a dense design space providing Commanders with an understanding of the possibilities and limitations of the deployed supply chain. An understanding of how legacy MALSP and MALSP II spare parts packages compare to ELAT provide a starting point to help explain how spare parts packages affect the supply effectiveness and response time. Conclusions are drawn from a comprehensive look at the metrics to provide the MALS with a training model.

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IV. RESULTS AND ANALYSIS

A. SCOPE

The analysis focuses on the results from the simulation and the MOEs. First, we examine the legacy MALSP and MALSP II spare parts packages and compare them to the ELAT output. Doing so gives us an idea of whether the packages have sufficient material to support the MALSP II style deployments. Next, we look at net supply effectiveness for the PMALS, MOB, and FOB and the effect the network configuration has on it. Finally, we look at response time and how the configurations impact the time to issue spare parts. This gives us insight into the effect of material deficiencies on system performance.

B. ANALYSIS OF LEGACY MALSP AND MALSP II SPARE PARTS PACKAGES

Analyzing the legacy MALSP and MALSP II spare parts packages provides insight into understanding the supportability of deployment configurations. As the number of nodes of the network and the number of deployed aircraft increase, more spare parts are needed, in general, to adequately support the squadrons. Tradeoffs must take place if the allowance for a particular item is insufficient to fill required buffers at each node.

First, we examine the total number of spare parts available for each package according to the AFAST data (see Table 3). Of note, Legacy MALSP, which relies on a "push" logistics network, contains considerably more spare parts than MALSP II, which is a "pull" logistics network. Disparity between the number of spare parts in the Legacy MALSP and MALSP II totals exist because of the combination of different packages used.

Table 3. Total number of spare parts by package

Total Number of spare parts	
Legacy	MALSP II
4110	2696

This thesis uses the ELAT algorithm with a high risk setting to determine the number of spare parts to be placed in the buffer for every node in each configuration. Recall that 954 NIINs had at least one demand in a two-year period according to the AFAST data. Of the 954 NIINs with demand, ELAT recommends at least one non-zero buffer for 564 NIINs. This is based on seventy-eight aircraft within the model. Table 4 provides a breakdown of NIINs, which contain at least one legacy MALSP or MALSP II allowance and an ELAT buffers. This table includes those items for which ELAT identifies at least one spare part as the ideal buffer. This does not mean the all buffers were filled. Also, the legacy MALSP and MALSP II packages contain more spare parts than those identified by ELAT. We find that the Legacy MALSP packages contain 81.3% of ELAT identified buffers while MALSP II contains 72.7%. Furthermore, both legacy MALSP and MALSP II packages contain more spare parts than ELAT suggests. The differences in the packages illustrate that NAVICP does not use ELAT when producing allowances.

Table 4. Number of NIINs which contain at least one legacy MALSP or MALSP II allowance and an ELAT buffer

NIINs in Package with ELAT Buffer	
Legacy	MALSP II
459	410
81.3%	72.7%

The legacy MALSP and MALSP II spare parts packages each contain NIINs which ELAT did not identify as required to support the flying squadrons. Table 5 displays the number of NIINs in the spare parts packages which were not identified by

ELAT. Interestingly, the legacy MALSP package contains fewer non-ELAT identified NIINs than MALSP II.

Table 5. Number of NIINs with allowances not identified by ELAT

NIINs With Allowances and Zero ELAT buffers	
Legacy	MALSP II
121	156

Figure 7 is a graphical representation of the number of NIINs by configuration where the quantity of spare parts is insufficient to meet the recommended ELAT buffer sizes. Most importantly, we notice that both legacy MALSP and MALSP II spare parts packages suffer from a substantial number of deficient NIINs, even for the simplest configurations. Legacy MALSP is short 121 spare parts out of 954 and MALPS II is short 170 out of 954 spare parts at configuration 1a. The number of deficient spare parts only increases as the complexity of the configurations increases.

In all cases legacy MALSP has fewer buffer sizes that do not match those of ELAT. Part of the reason for this is the larger size with respect to quantity of spare parts than MALSP II as shown in Table 3 Even though MALSP II has 1,114 fewer spare parts than legacy MALSP, the difference with respect to deficient NIINs is relatively close. Notice the MALSP II quantities of spare parts begin to separate further from legacy MALSP spare parts packages at configuration 8a and beyond. Configuration 8a contains almost two fully deployed squadrons. Configuration 9a and 11a support two fully deployed squadrons and an ESB and lastly, configuration 10a supports two deployed squadrons without an ESB, which accounts for the small drop in deficient NIINs. The high TRR also requires more spare parts to cover the larger shipping times.

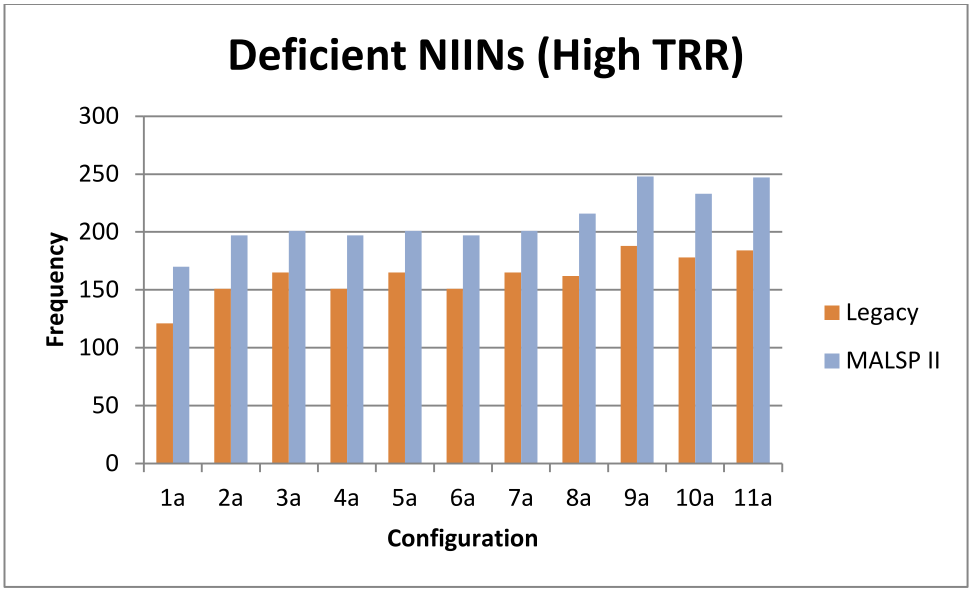

Figure 7. Number of NIINs with deficient spare parts quantities by configuration with high TRR (complexity increases from left to right)

Next, we consider the deficient NIINs by configuration with low TRR. In Figure 8 we can see that fewer NIINs are required in all cases compared to the high TRR example. We also see that both legacy MALSP and MALSP II are relatively consistent in deficiency in all configurations except 11a. In configuration 11a, with an ESB and two deployed squadrons, the quantity of spare parts appears to stretch more thinly than all the smaller configurations.

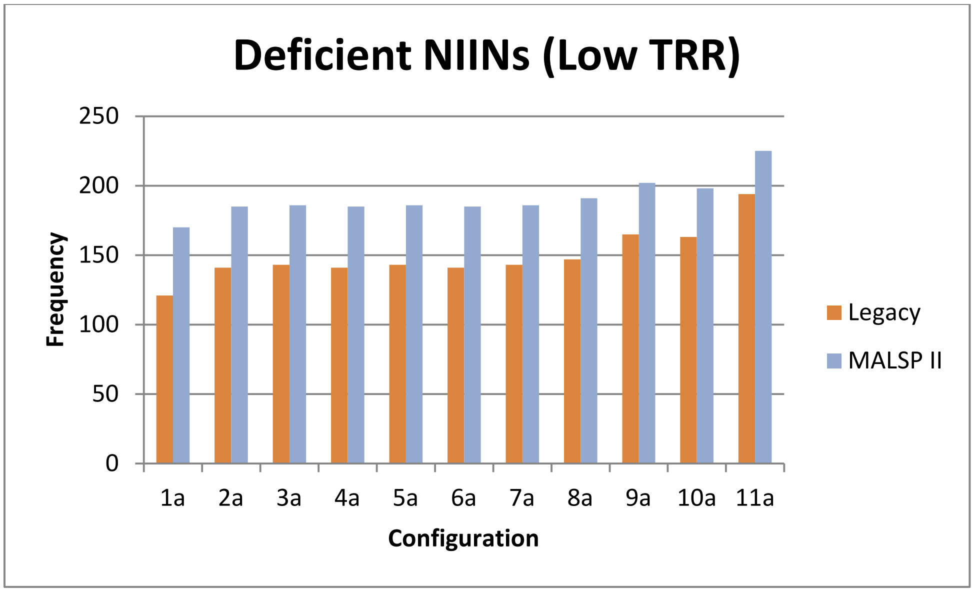

Figure 8. Number of NIINs with deficient spare parts quantities by configuration with low TRR

Figure 9 graphically displays the number of NIINs which have Legacy MALSP or MALSP II spare parts packages which are deficient compared to ELAT at high TRR. This is an important difference between Figure 7 and Figure 8 where we examine all NIINs. Figure 9 investigates the net effectiveness features, which are NIINs that the supply department maintains allowances. The number of deficient NIINs at low TRR noticeable increase again at configuration 9a where MALSP II spare parts packages experience a dramatic rise in deficiencies.

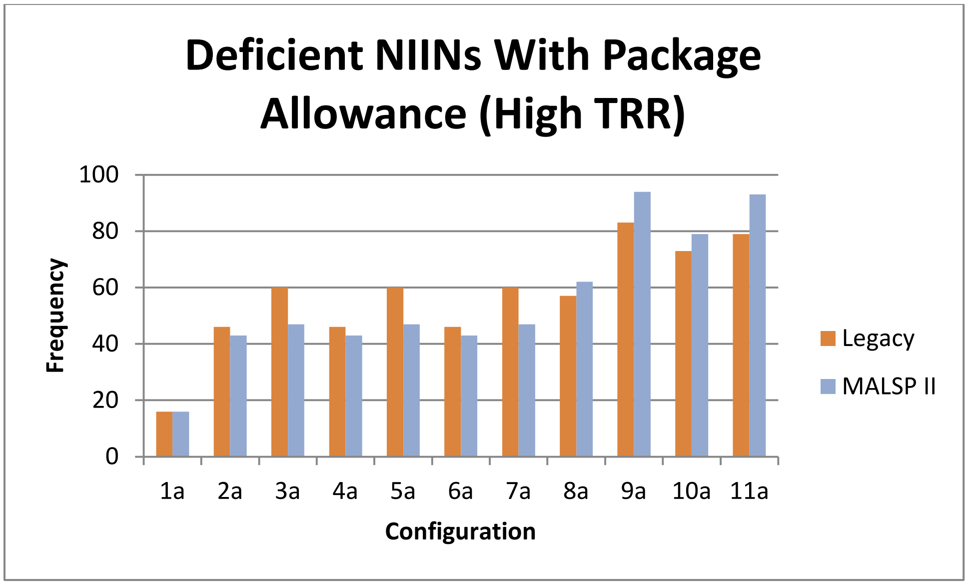

Figure 9. Deficient NIINs with spare parts quantities that do not cover ELAT buffer size with high TRR (954 total NIINs considered)

The TRR is an important factor to consider when analyzing spare parts quantities for support packages. In Figure 10 we see the effect of the low TRR compared to high TRR in Figure 9 with respect to deficient NIINs with Legacy MALSP or MALSP II spare parts packages. In both figures, configuration 1a has the same number of deficient NIINs because the TRR is not impacted by shipping spare parts between nodes. We see fewer deficient NIINs because of smaller buffer requirements. We also see that MALSP II spare parts packages have dramatic increases in deficient NIINs at configuration 9a and beyond. Figure 10 suggests that fewer spare parts are needed to cover ELAT buffer sizes when TRR is lower, which is consistent with MALSP II methodology.

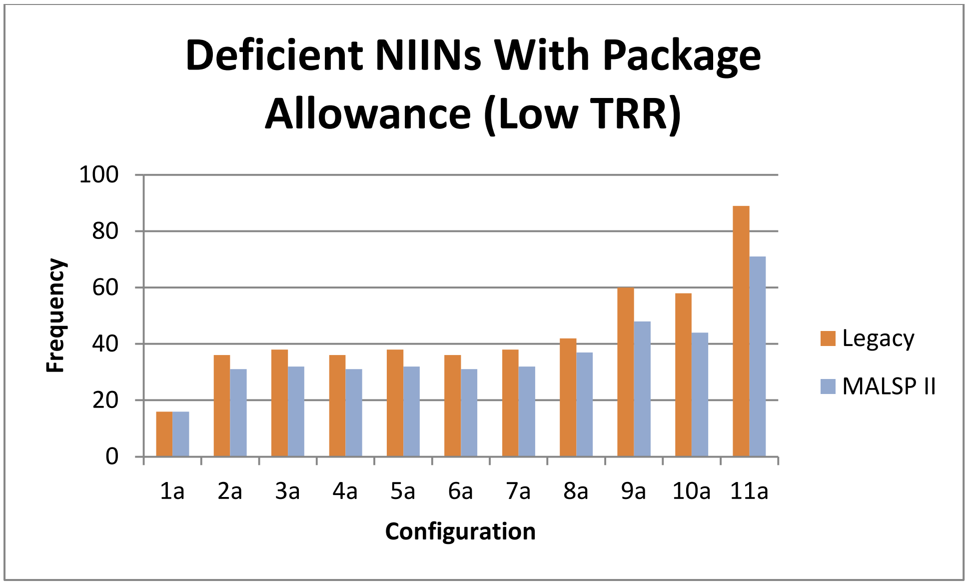

Figure 10. Deficient NIINs with spare parts package quantities that do not cover ELAT buffer size with low TRR

Both legacy MALSP and MALSP II packages contain a considerable amount of deficient NIINs. Next we analyze the supply effectiveness and response time to get a better understanding of the effect of deficient NIINs.

C. RESULTS OF THE NET SUPPLY EFFECTIVENESS MOE

Net supply effectiveness is currently how supply departments are graded. Recall that net supply effectiveness only includes NIINs for which the supply department has allowances. The calculation is therefore, number of immediate issues from the node to the squadron divided by the number of demands. First, we look at the net supply effectiveness of the PMALS and how configurations affect the net effectiveness at the PMALS.

Figure 11 is a graphical display of how supply effectiveness at the PMALS decreases as aircraft are deployed. As spare parts are spread out to fill the buffers sizes at each node, the net supply effectiveness at each of the nodes begin to decrease. Legacy MALSP and MALSP II packages performance appear closely matched over all the configurations. A one-way Analysis of Variance (ANOVA) test reveals that the

difference between legacy MALSP and MALSP II is statistically significant (p-value < 0.001).

We also see that beginning at configuration 8a, the net supply effectiveness for MALSP II begins to decrease, which is also confirmed in Table 6. Table 6 is produced from the one-way ANOVA with a Tukey-Kramer comparison of means test. Refer to the Appendix for all one-way ANOVA with Tukey-Kramer comparison of means test data. All connecting letter report tables, which show statistical significance in this chapter, are produced in the same manner. If the letters in the connecting letters report are the same then the difference in means is not statistically significant. If the letters in the report are different then the means are statistically significant. From configuration 1a to 7a, the differences in net supply effectiveness at the PMALS are not statistically significant. In configuration 9a and 11a, the ESB causes significant drops in net supply effectiveness at the PMALS because of the allowances that are allocated to the ESB, thus taking away spare parts from the nodes capable of immediate issues, which increase net supply effectiveness.

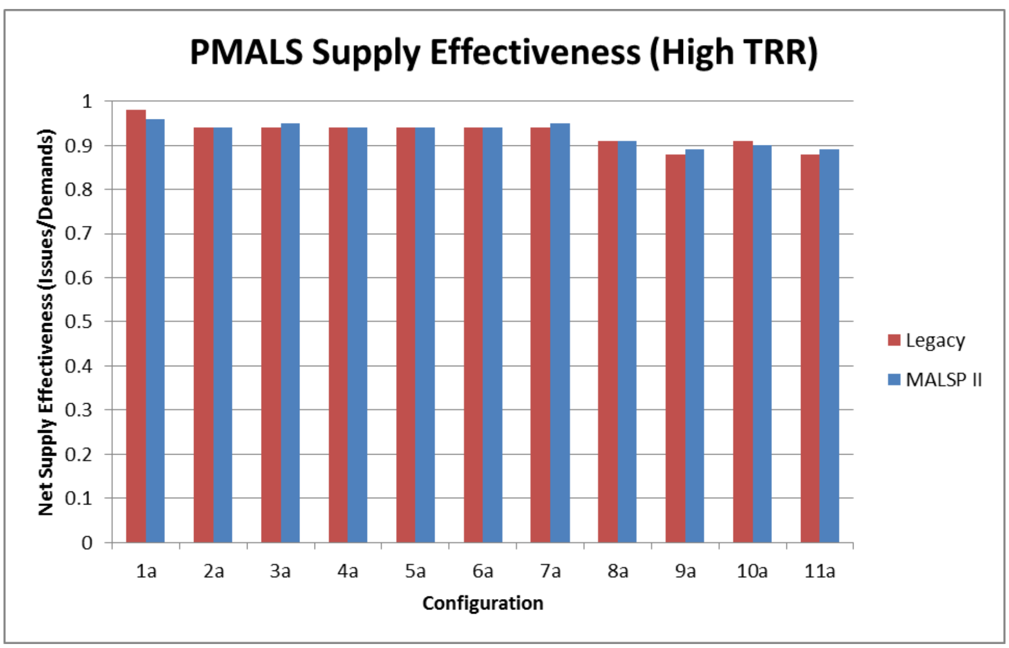

Figure 11. PMALS supply effectiveness with high TRR

Table 6. MALSP II PMALS supply effectiveness with low TRR connecting letters report

Connecting Letters Report			
Configuration			Mean
7a	A		0.95
3a	A		0.95
6a	A		0.94
5a	A		0.94
2a	A		0.94
4a	A		0.94
8a		B	0.91
10a		B	0.90
9a		B	0.89
11a		B	0.89

In Figure 12 we examine the effects of TRR on the net supply effectiveness at the PMALS. As expected, the net supply effectiveness at the PMALS is higher with low TRRs. This makes sense as spare parts travel more quickly between nodes to replenish the buffers. The effect of the ESB on net supply effectiveness is still noticeable at configurations 9a and 11a and confirmed in the connecting letters report in Table 7. Recall that the ESB is a node in between the PMALS and MOB. Interestingly, net supply effectiveness is reduced with the addition of the ESB because spare parts at the ESB cannot be immediately issued. The spare parts at the ESB are closer to deployed nodes, but if greater demand is experienced at the deployed nodes than expected, the deployed nodes are not replenished in time to make and immediate issue. Hence, net supply effectiveness is reduced by storing parts at the ESB at the expense of other nodes.

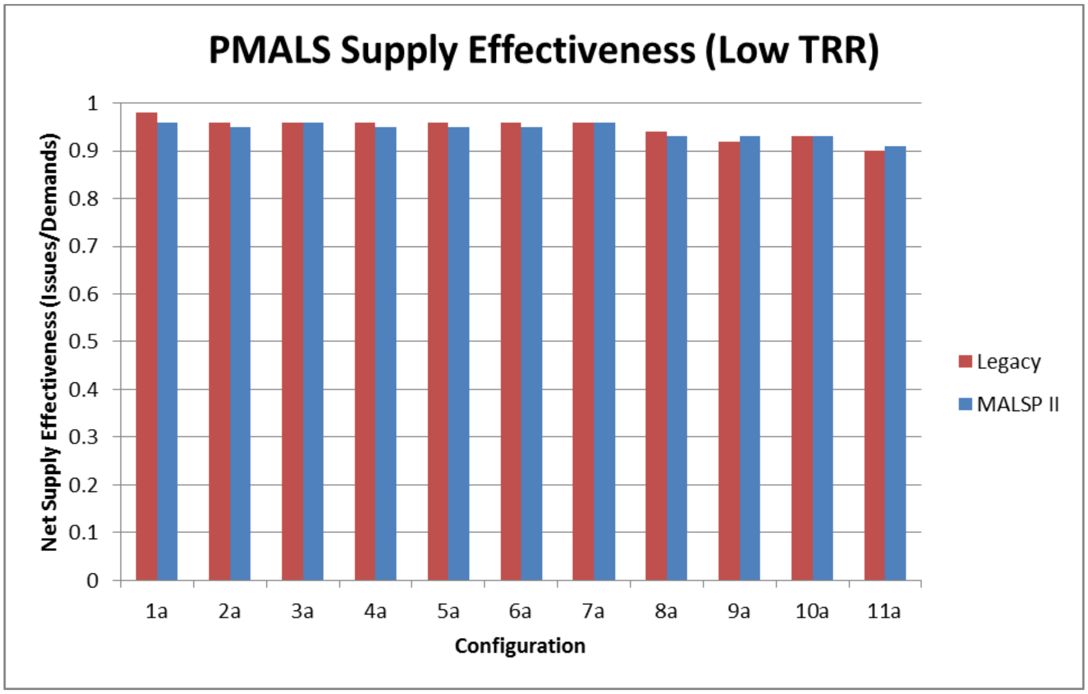

Figure 12. PMALS supply effectiveness with low TRR

Table 7. MALSP II, PMALS supply effectiveness with low TRR connecting letters report

Connecting Letters Report						
Configuration						Mean
7a	A					0.96
3a	A					0.96
6a	A					0.95
2a	A	B				0.95
5a	A	B	C			0.95
4a	A	B	C			0.95
8a		B	C	D		0.93
9a			C	D	E	0.93
10a				D	E	0.93
11a					E	0.91

Next, we analyze the net supply effectiveness of the MOBs and the FOBs. Note that configuration 1a is not present because that configuration only includes a PMALS. In Figure 13 we see that net supply effectiveness of the odd numbered configurations (with an ESB) are always less than those configurations without an ESB. The high risk spare part distribution and limited allowances negatively affect the net supply effectiveness when the ESB is included. Surprisingly, configuration 8a has the highest net supply effectiveness which is statistically significant as seen in Table 8. This is in part because the MOB1 has a higher priority for spare parts than the PMALS and attracts the low density allowanced spare parts and the PMALS supports fewer aircraft than the prior configurations, causing more spare parts to be included in the MOB1 buffer.

The MOB1 net supply effectiveness is similar at high TRR as it is at low TRR, therefore the graph is not displayed. The MOB1 net supply effectiveness is also similar to MOB2 and is not necessary to graphically display.

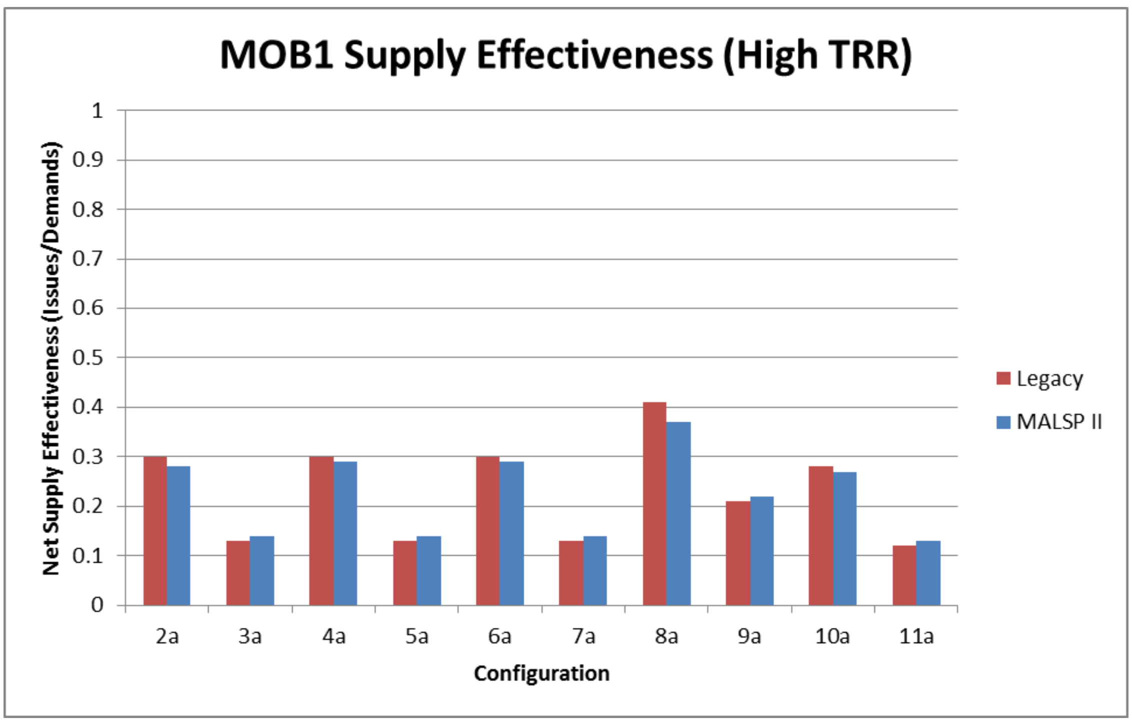

Figure 13. MOB1 supply effectiveness at high TRR by configuration

Table 8. MALSP II, MOB1 supply effectiveness with low TRR connecting letters report

Connecting Letters Report					
Configuration					Mean
8a	A				0.41
4a		B			0.30
6a		B			0.30
2a		B			0.30
10a		B			0.28
9a			C		0.21
5a				D	0.13
7a				D	0.13
3a				D	0.13
11a				D	0.12

The final piece to understanding how the different configurations and allowancing affect net supply effectiveness is to analyze the FOB. All the FOBs have similar net supply effectiveness and we therefore look at only FOB1. We notice that the net supply effectiveness is extremely low, almost negligible for all configurations. The reason is simply that ELAT provides few buffers to the FOBs because the TRR was low enough that spare parts arrive from other nodes quickly enough to not stock the buffers, because of the way demand was calculated in the model. Recall from Chapter III how demand was distributed as a proportion of aircraft throughout the model. Because the FOBs have so few spare parts, immediate issues from the FOB seldom occur.

The net supply effectiveness MOE decreases as complexity of the configurations increases. Therefore, deficient NIINs negatively impact supply effectiveness because as the number of nodes increases, there are not enough spare parts to fill the ELAT suggested buffers. Also, the addition of the ESB significantly reduces net supply effectiveness, especially at the deployed nodes. Next we analyze response time to get a better understanding of the whole supply chain network.

D. RESULTS OF THE RESPONSE TIME MOE

Analyzing the response time of each configuration provides insight into the effects of TRR and the proper location for spare parts. Instead of ensuring each node has more spare parts to make immediate issues which increases supply effectiveness; we focus on the time it takes to ship spare parts to the nodes where the gear is required. First, we investigate the gross response time for each configuration with high TRR and low TRR. Then we consider the net response time to analyze the effect of demand when spare parts are present at the nodes.

In Figure 14 we see that the response time increases as complexity of the configurations increases. Also, the odd nodes with the exception of 1a (PMALS only), contain the ESB which considerably drives up the response time as complexity increases. Also, legacy MALSP response times are less than MALSP II response times in all configurations. This is because the greater number of spare parts contained in the legacy MALSP package ensure greater quantities of parts are available in the model. Recall that the legacy MALSP packages have 1,414 more spare parts than the MALSP II packages which suggests the MALSP II packages have fewer allowances at each node and perform closely to legacy MALSP, at less complex configurations. We only consider the statistical significance of the MALSP II packages because this is the focus of this thesis.

As expected, configuration 1a (PMALS only) has the lowest response time because all aircraft are supported in a single location. Again the configurations containing the ESB have statistically significant higher response times than the same configuration without an ESB (see Figure 11). Configuration 8a has the second best statistically significant response. Overall the response time tends to increase with complexity with the exception of configuration 8a.

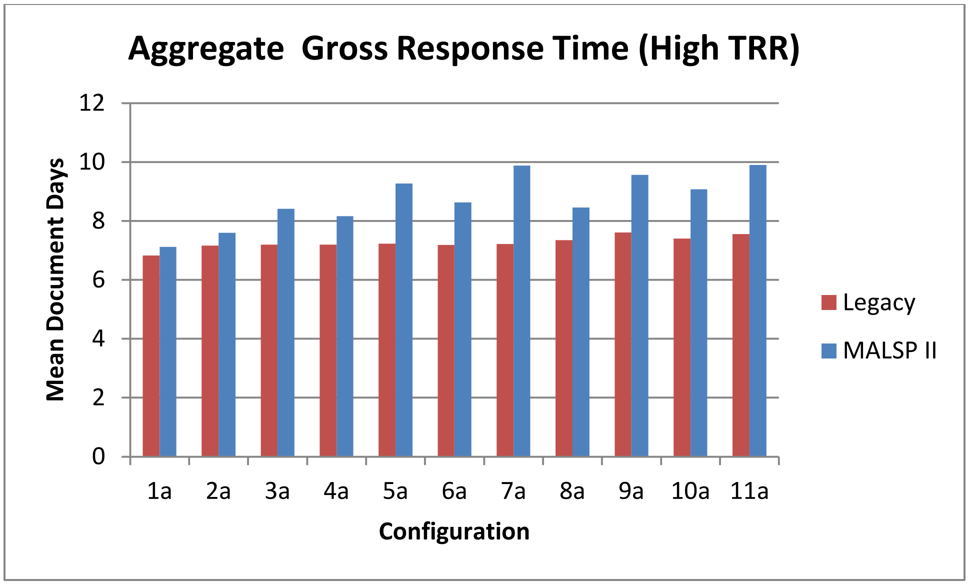

Figure 14. Gross Response time with high TRR by configuration

Table 9. MALSP II, Aggregate gross response time with high TRR connecting letters report

Connecting Letters Report								
Configuration								Mean
11a	A							9.91
7a	A	B						9.88
9a		B	C					9.57
5a			C	D				9.27
10a				D				9.08
6a					E			8.63
8a					E	F		8.45
3a					E	F		8.41
4a						F		8.17
2a							G	7.60

Next, we examine the aggregate net response produced by the simulation. Recall that net response time only includes those NIINs for which allowances exist within the packages. We see that the net response time is significantly less than the gross response time because the gross response time includes spare parts without allowances. When spare parts do not have allowances, the time to ship them to the node is significantly increased because all parts are originating from the wholesale system.

Figure 15 shows a graphical representation of the net response time with high TRR by configuration. We see that response time increases in both Legacy MALSP and MALSP II packages as the number of deployed aircraft increases. The ESB, again negatively affects the response time in a statistically significant way, as seen in Table 10 by holding spare parts which are not directly supporting aircraft at nodes. Of note, the response time at configuration 1a approaches zero when only observing those NIINs with package allowances. This is primarily due to the fact that all spare parts are maintained at the PMALS to support all seventy-eight aircraft. Again net response time at low TRR is similar in shape to the high TRR. The mean document days are less with lower TRR, but proportional to the high TRR plot.

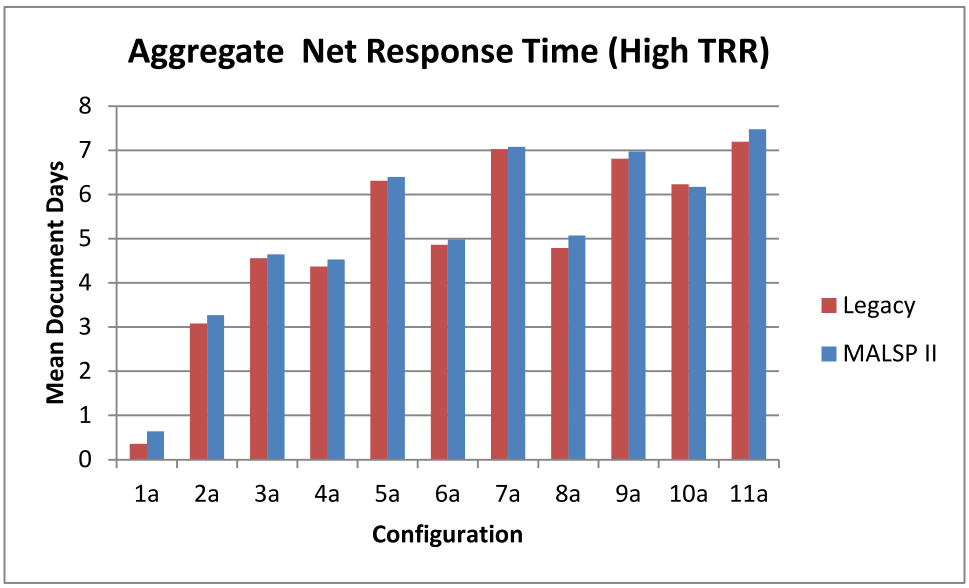

Figure 15. Aggregate net response time with high TRR by configuration

Table 10. MALSP II, Aggregate net response time with high TRR connecting letters report

Connecting Letters Report							
Configuration	[redacted]						Mean
11a	A						7.48
7a		B					7.08
9a		B					6.97
5a			C				6.40
10a			C				6.17
8a				D			5.08
6a				D			4.98
3a				D	E		4.65
4a					E		4.53
2a						F	3.27

We are interested in analyzing the effects of configuration complexity on PMALS performance. We want to ensure that the PMALS have enough spare parts to effectively train while the deployed squadrons also have enough spare parts to fly combat missions. From Figure 16 we see that adding additional nodes more than doubles the response time at the PMALS. The same effect is exacerbated with MALSP II packages due to the fewer quantities of spare parts which reside at the PMALS. Table 11 shows that configurations 2a through 7a are not significantly significant.

At configuration 8a we see a dramatic increase in the response time at the PMALS. Configuration 8a is where the lack of spare parts really affects the PMALS response time. The deployed nodes in configuration 8a require more spare parts and cannot keep up with demand. Of note, configurations 3a, 5a, and 7a actually show a decrease in response time with the ESB included at the PMALS. The ESB decreases the response time at the PMALS because the spare parts are closer to the PMALS to resupply the buffers. The more complex configurations with the ESB, however, significantly decrease response time.

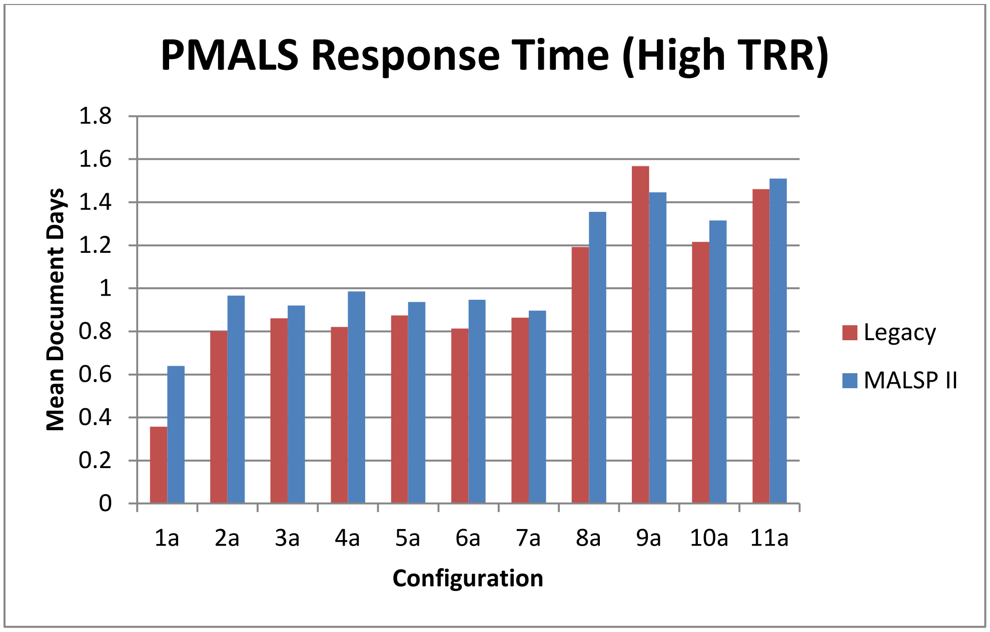

Figure 16. PMALS net response time with high TRR by configuration

Table 11. MALSP II, PMALS net response time with high TRR connecting letters report

Connecting Letters Report					
Configuration					Mean
11a	A				1.51
9a	A				1.45
8a	A	B			1.36
10a	A	B	C		1.31
4a		B	C	D	0.99
2a		B	C	D	0.97
6a			C	D	0.95
5a			C	D	0.94
3a			C	D	0.92
7a				D	0.90

Next, we analyze the response time at the deployed nodes, the MOBs and the FOBs. Note that configuration 1a is not present because that configuration does not include a MOB1. The response time at the ESB is always zero because it does not immediately issue spare parts to aircraft.

In Figure 17 we see that response time of the odd numbered configurations (with an ESB) are always greater than those configurations without an ESB. The high risk spare part distribution and limited quantities of spare parts negatively affect the net response time when the ESB is included. Surprisingly, configuration 8a has the lowest net response time which is statistically significant as seen in Table 12. This is in part because MOB1 has a higher priority for spare parts than the PMALS and attracts the low density allowanced spare parts and the PMALS supports fewer aircraft than the prior configurations, causing more spare parts to be included in the MOB1 buffer.

The MOB1 response time is proportional at high TRR as it is at low TRR, therefore the graph is not displayed. The MOB1 net response time is also similar to MOB2 and is not necessary to display.

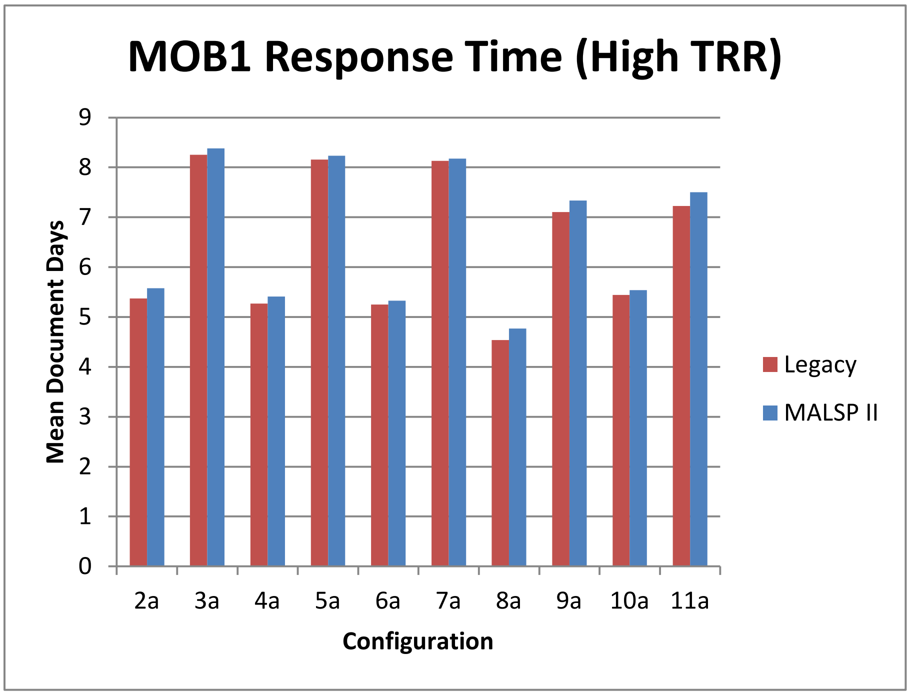

Figure 17. MOB1 net response time with high TRR by configuration

Table 12. MALSP II, MOB1 net response time with high TRR connecting letters report

Connecting Letters Report					
Configuration	[redacted]				Mean
3a	A				8.38
5a	A				8.23
7a	A				8.17
11a		B			7.50
9a		B			7.34
2a			C		5.58
10a			C		5.54
4a			C	D	5.41
6a			C	D	5.33
8a				D	4.77

The final piece to understanding how the different configurations and allowancing affect net response time is to analyze the FOB. All the FOBs have similar net response times, therefore; we only look at FOB1. Figure 18 graphically displays the FOB1 net response times by configuration. We notice that the odd numbered configurations with an ESB significantly increase response time at FOB1. We also notice that configuration 10a has a significantly higher response time than all other configurations without an ESB.

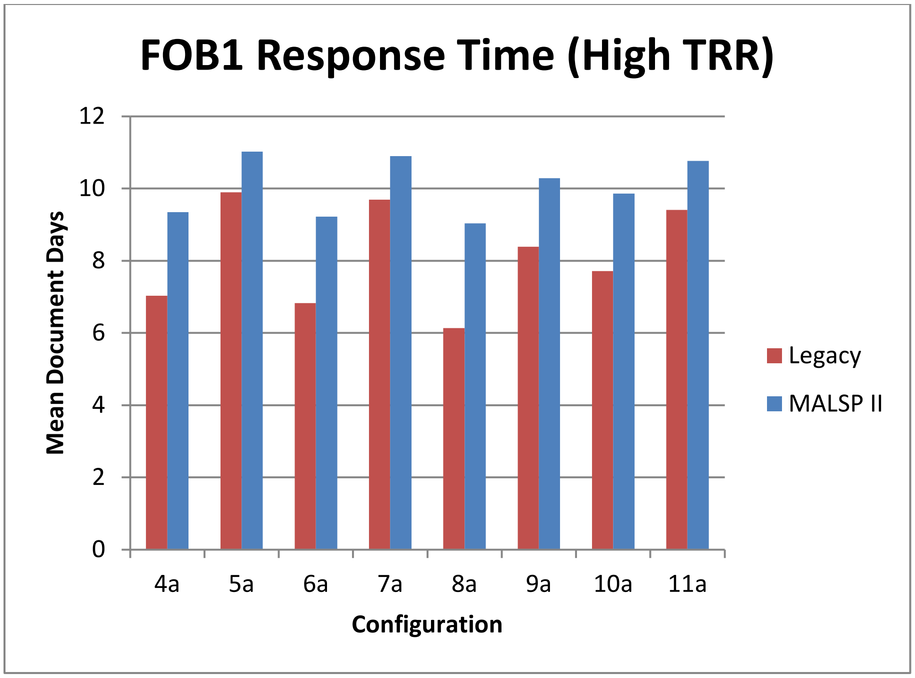

Figure 18. FOB1 net response time with high TRR by configuration

Table 13. MALSP II, FOB1 net response time with high TRR connecting letters report

Connecting Letters Report					
Configuration					Mean
5a	A				11.02
7a	A				10.90
11a	A	B			10.76
9a		B	C		10.29
10a			C		9.86
4a				D	9.34
6a				D	9.22
8a				D	9.04

E. SUMMARY

The net response time MOE allows us to examine the amount of time aircraft wait for spare parts on average. This MOE provides information on the overall responsiveness of the supply chain network. Deficient NIINs contribute significantly to higher net response times because the buffers do not get replenished in a timely manner. Also, the ESB causes higher net response times because of the quantity of deficient NIINs and the ESB does not directly provide spare parts to aircraft.

We now have a better understanding of how legacy MALSP and MALSP II spare part packages perform with respect to deficient NIINs, net supply effectiveness, and response time. In general, as configurations become more complex the MOEs decrease in effectiveness. We use this information to draw conclusions and make recommendations.

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V. CONCLUSIONS

This thesis uses Java based discrete event simulation of a MALSP II designed nodal supply chain to gain insight into the canonical deployment structure. This provides aviation logisticians with a better understanding of the capabilities and performance with respect to spare parts support for different configurations and a model for which to train.

The aviation logistician does not always have all the spare parts to fill all the buffers, even with high-risk allowancing. Therefore, decisions have to made on which node has priority when spare parts are scarce. Number of aircraft and location of the deployed aircraft also factor into the decision making process. The ultimate goal is achieving a high level of effective spare part support for flying aircraft.

We analyze different aircraft configurations with a full factorial design. We gain insight by examining three MOEs—deficient NIINs, supply effectiveness, and response time. All three MOEs include gross analysis where all demands are considered and net analysis where only demands with package allowances are considered. We examine legacy MALSP and MALSP II packages side by side to inform the impact of previous and proposed future allowances, respectively. All NIINs and configurations are further tested with high and low TRR to answer the following research objectives:

(1) Develop and assess a canonical MALSP II style deployment.

a. Conclusion

Spare parts are limited, and even with high risk demand filtering, not all ELAT suggested buffers are filled. The main factors that affect the MOE are number and placement of spare parts and TRR. In general, as TRR decreases, supply effectiveness and response times improve. Interestingly, the ESB negatively affects supply effectiveness and response time because spare parts are taken from other nodes where immediate issues are made.

Configuration 8a is in the second tier of statistical significance with deficient NIINs and not nearly as lacking as configurations 9a, 10a, and 11a. Configuration 8a is in the third tier of statistical significance with respect to the PMALS net supply

effectiveness, however performs the best at the deployed nodes. Configuration 8a also achieves the best balance with response time as it is in the third tier at the PMALS, but lowest response time at the deployed nodes.

b. Recommendation

Recommend that the Marine Corps aviation logistics community adopts Configuration 8a (PMALS, MOB, three FOBs; with 10 aircraft) as the canonical MALSP II deployment structure. Configuration 8a provides enough coverage for a wide range of operations with one MOB and three FOBs while less complex configurations are also supportable. Overall quantity of repairable components should be reassessed if a similar deployment to configuration 9a or greater is expected.

(2) Evaluate the MV-22 spare parts allowances effectiveness with multiple Forward Operating Bases.

a. Conclusion

MV-22 MALSP II packages decrease in effectiveness as the nodes and number of supported aircraft become more complex. The legacy MALSP package also contains 1,414 more spare parts than MALSP II, but from a practical perspective the MALSP II packages perform about the same as the legacy MALSP packages. This demonstrates that having more spare parts does not necessarily ensure better performance. Conversely, fewer spare parts per NIIN cannot always fill the buffer sizes proposed by ELAT. A disconnect between the method spare parts SPO/ARROW allowances and buffers ELAT computes contributes to deficient NIINs. MALSP II and legacy MALSP spare parts packages both perform poorly with respect to the supply effectiveness MOE because low demand for only two aircraft at the FOB result in very few spare parts at the FOB.

b. Recommendation

Repairable spare parts are not recommended to be stored at the ESB due to limited quantities and the negative effects on all MOEs. Also, the NAVICP allowancing method needs to be reevaluated in order to more closely align with current Marine aviation logistics support.

The following are recommendations for follow-on research:

1. The focus of this thesis is spare parts, specifically high priority repairable components. Adding consumable components more closely resembles a real world aviation logistics deployment. Consumable spare parts are not as closely regulated in terms of the number of spare parts a MALS can carry and therefore the effect of the ESB could be better analyzed.

2. This thesis only considers spare parts and how the allowances impact the aviation supply MOEs. Including the support equipment requirements and personnel would also help explain which deployment configurations are supportable.

3. Average spare part demand data in this thesis was characterized by daily demand per aircraft. The two aircraft at some of the FOBs had an extremely small μ, causing ELAT to select very few spare parts. Another method to project demand data could provide more insight into more realistic spare parts packages at the FOBs.

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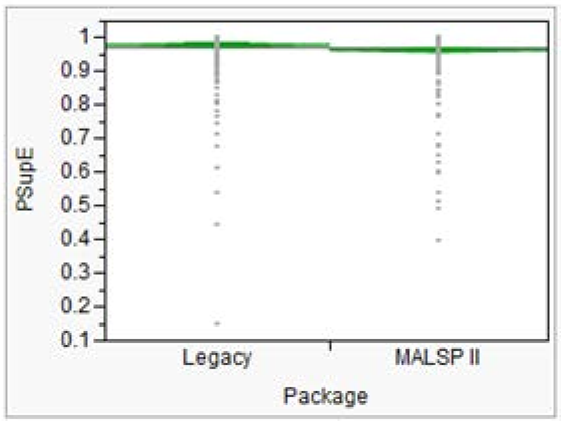
APPENDIX.

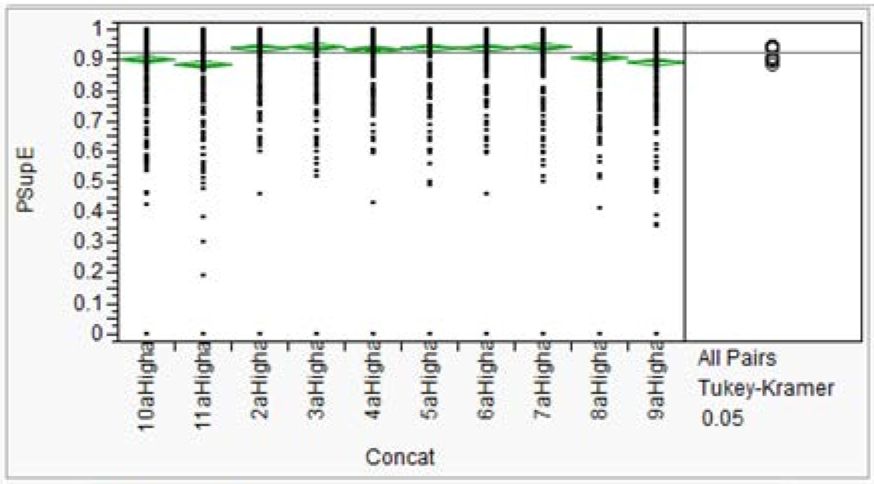
The items in this section were used to produce the graphs and connecting letter reports seen in Chapter IV. All graphs are the product of one-way ANOVA and Tukey-Kramer comparison of means.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Package	1	0.0739030	0.073903	13.4819	0.0003*
Error	1144	6.2709930	0.005482		
C. Total	1145	6.3448960			

Figure 19. One-way ANOVA and Tukey-Kramer comparison of means analysis of the aggregate PMALS supply effectiveness comparison of legacy MALSP and MALSP II

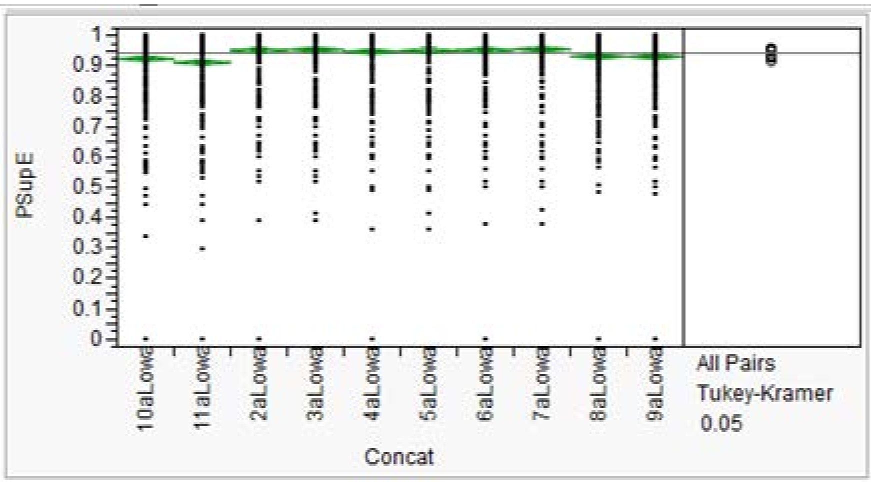


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	566	0.904148	0.00594	0.89250	0.91580
11aHigha	566	0.887349	0.00594	0.87570	0.89900
2aHigha	566	0.941206	0.00594	0.92955	0.95286
3aHigha	566	0.945161	0.00594	0.93351	0.95681
4aHigha	566	0.937059	0.00594	0.92541	0.94871
5aHigha	566	0.941424	0.00594	0.92977	0.95308
6aHigha	566	0.941677	0.00594	0.93002	0.95333
7aHigha	566	0.945851	0.00594	0.93420	0.95750
8aHigha	566	0.909568	0.00594	0.89792	0.92122
9aHigha	566	0.894271	0.00594	0.88262	0.90592

Std Error uses a pooled estimate of error variance

Figure 20. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II PMALS supply effectiveness with high TRR used in Figure 11 and Table 6

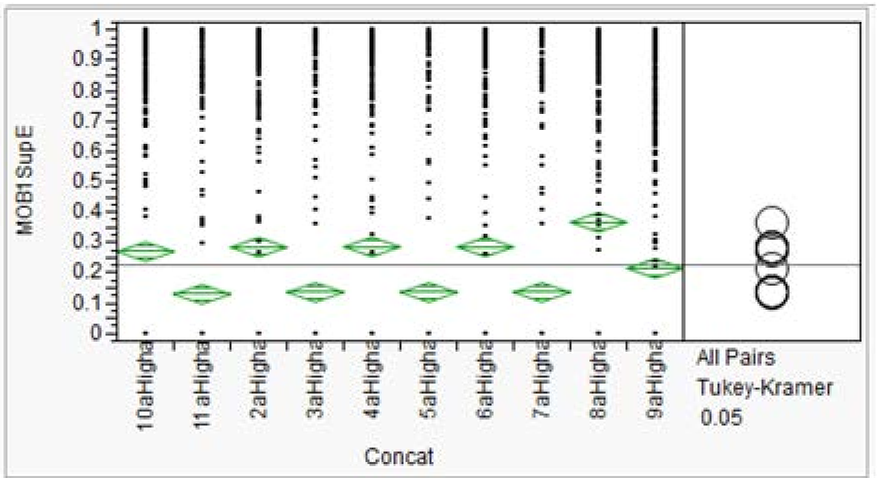


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aLowa	566	0.925315	0.00449	0.91650	0.93413
11aLowa	566	0.912756	0.00449	0.90394	0.92157
2aLowa	566	0.952635	0.00449	0.94382	0.96145
3aLowa	566	0.955597	0.00449	0.94679	0.96441
4aLowa	566	0.948954	0.00449	0.94014	0.95777
5aLowa	566	0.951999	0.00449	0.94319	0.96081
6aLowa	566	0.953546	0.00449	0.94473	0.96236
7aLowa	566	0.956870	0.00449	0.94806	0.96568
8aLowa	566	0.932953	0.00449	0.92414	0.94176
9aLowa	566	0.932425	0.00449	0.92361	0.94124

Std Error uses a pooled estimate of error variance

Figure 21. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II PMALS supply effectiveness with low TRR used in Figure 12 and Table 7

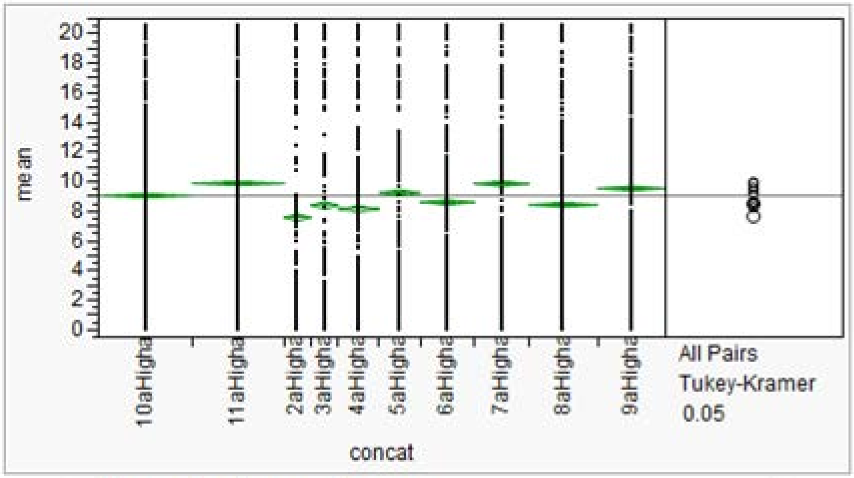


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	580	0.277500	0.01474	0.24861	0.30639
11aHigha	580	0.117616	0.01474	0.08872	0.14651
2aHigha	580	0.301020	0.01474	0.27213	0.32991
3aHigha	580	0.129986	0.01474	0.10109	0.15888
4aHigha	580	0.303141	0.01474	0.27425	0.33203
5aHigha	580	0.130628	0.01474	0.10174	0.15952
6aHigha	580	0.302584	0.01474	0.27369	0.33148
7aHigha	580	0.130495	0.01474	0.10160	0.15939
8aHigha	580	0.407130	0.01474	0.37824	0.43602
9aHigha	580	0.206539	0.01474	0.17765	0.23543

Std Error uses a pooled estimate of error variance

Figure 22. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II MOB1 supply effectiveness with high TRR used in Figure 13 and Table 8

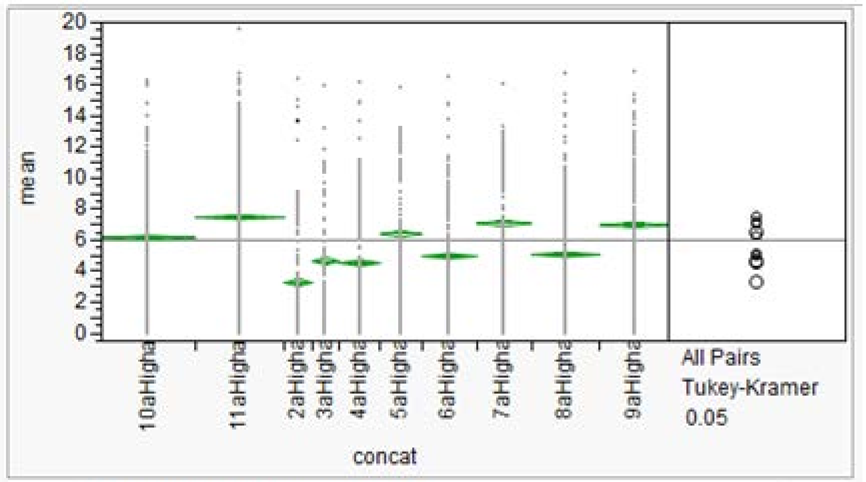


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	6573	9.07569	0.06417	8.9499	9.201
11aHigha	6399	9.90517	0.06504	9.7777	10.033
2aHigha	1908	7.59712	0.11911	7.3637	7.831
3aHigha	1908	8.41464	0.11911	8.1812	8.648
4aHigha	2862	8.16570	0.09725	7.9751	8.356
5aHigha	2862	9.27351	0.09725	9.0829	9.464
6aHigha	3816	8.63447	0.08423	8.4694	8.800
7aHigha	3816	9.88221	0.08423	9.7171	10.047
8aHigha	4770	8.45304	0.07533	8.3054	8.601
9aHigha	4770	9.56712	0.07533	9.4195	9.715

Std Error uses a pooled estimate of error variance

Figure 23. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II aggregate gross response time with high TRR used in Figure 14 and Table 9

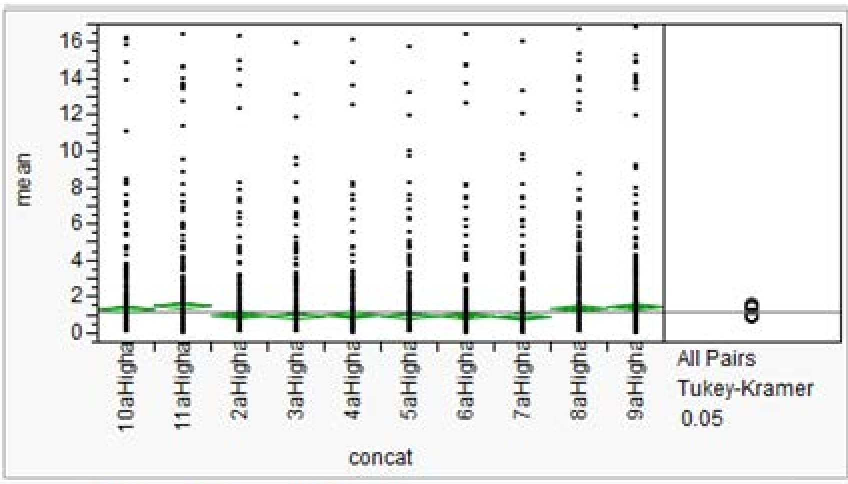


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	3857	6.17154	0.06843	6.0374	6.3057
11aHigha	3683	7.47552	0.07003	7.3383	7.6128
2aHigha	1132	3.27131	0.12632	3.0237	3.5189
3aHigha	1132	4.64924	0.12632	4.4016	4.8968
4aHigha	1698	4.53257	0.10314	4.3304	4.7347
5aHigha	1698	6.39980	0.10314	6.1976	6.6020
6aHigha	2264	4.97832	0.08932	4.8032	5.1534
7aHigha	2264	7.08140	0.08932	6.9063	7.2565
8aHigha	2830	5.07681	0.07989	4.9202	5.2334
9aHigha	2830	6.97056	0.07989	6.8140	7.1272

Std Error uses a pooled estimate of error variance

Figure 24. One-way ANOVA and Tukey-Kramer comparison of means analysis of aggregate net response time with high TRR used in Figure 15 and Table 10

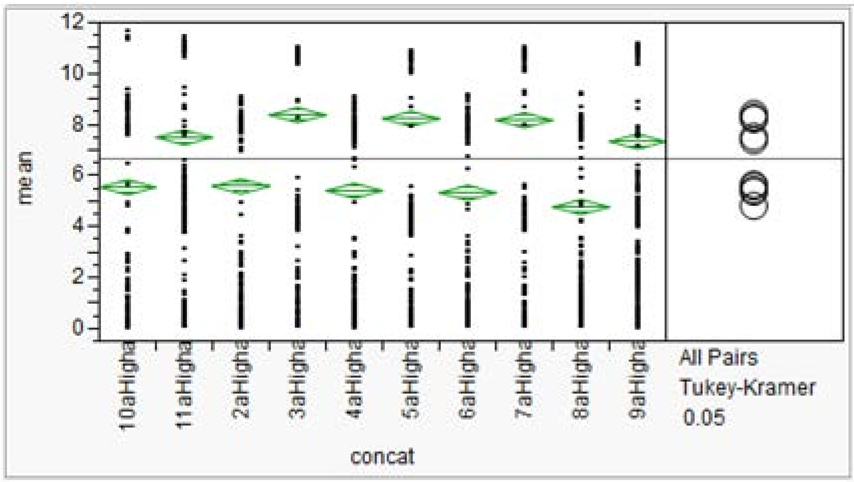


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	566	1.31497	0.09065	1.1373	1.4927
11aHigha	566	1.50997	0.09065	1.3323	1.6877
2aHigha	566	0.96590	0.09065	0.7882	1.1436
3aHigha	566	0.91993	0.09065	0.7422	1.0976
4aHigha	566	0.98507	0.09065	0.8074	1.1628
5aHigha	566	0.93636	0.09065	0.7586	1.1141
6aHigha	566	0.94701	0.09065	0.7693	1.1247
7aHigha	566	0.89670	0.09065	0.7190	1.0744
8aHigha	566	1.35529	0.09065	1.1776	1.5330
9aHigha	566	1.44541	0.09065	1.2677	1.6231

Std Error uses a pooled estimate of error variance

Figure 25. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II PMALS net response time with high TRR used in Figure 16 and Table 11

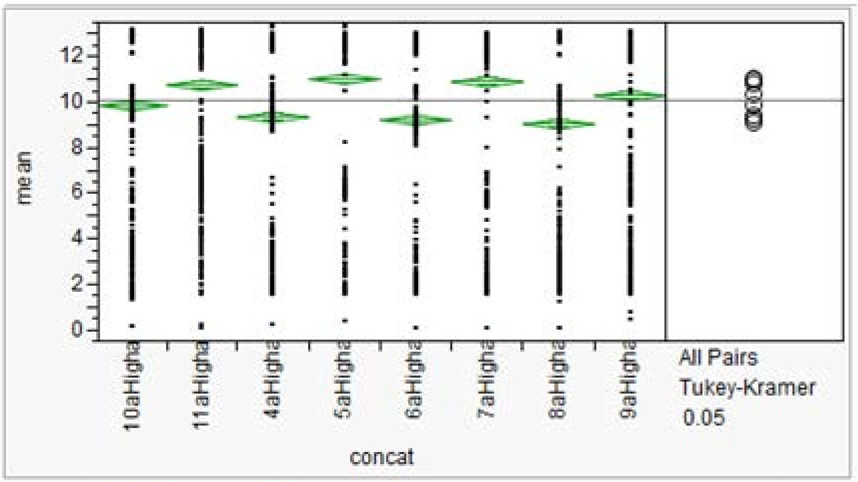


Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	566	5.54171	0.14971	5.2482	5.8352
11aHigha	566	7.49976	0.14971	7.2063	7.7933
2aHigha	566	5.57671	0.14971	5.2832	5.8702
3aHigha	566	8.37856	0.14971	8.0851	8.6721
4aHigha	566	5.40811	0.14971	5.1146	5.7016
5aHigha	566	8.23290	0.14971	7.9394	8.5264
6aHigha	566	5.32665	0.14971	5.0332	5.6201
7aHigha	566	8.17378	0.14971	7.8803	8.4673
8aHigha	566	4.76811	0.14971	4.4746	5.0616
9aHigha	566	7.33763	0.14971	7.0441	7.6311

Std Error uses a pooled estimate of error variance

Figure 26. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II MOB1 net response time with high TRR used in Figure 17 and Table 12



Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
10aHigha	915	9.8575	0.11406	9.634	10.081
11aHigha	939	10.7597	0.11259	10.539	10.980
4aHigha	954	9.3427	0.11170	9.124	9.562
5aHigha	954	11.0191	0.11170	10.800	11.238
6aHigha	954	9.2177	0.11170	8.999	9.437
7aHigha	954	10.8951	0.11170	10.676	11.114
8aHigha	954	9.0386	0.11170	8.820	9.258
9aHigha	954	10.2884	0.11170	10.069	10.507

Std Error uses a pooled estimate of error variance

Figure 27. One-way ANOVA and Tukey-Kramer comparison of means analysis of MALSP II MOB1 net response time with high TRR used in Figure 18

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